Eastern Bering Sea
Walleye Pollock Stock Assessment

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Summary

The primary focus of this chapter is on the eastern Bering Sea region. The Aleutian Islands Region and Bogoslof Island area are treated separately in Sections 1.15 and 1.16 on pages 85 and 88, respectively.

Changes in the input data
The 2001 NMFS bottom-trawl survey estimates of population numbers-at-age were available for analysis in this assessment. In terms of biomass, the bottom-trawl survey estimate for 2001 is 4.14 million tons, down by 19.5% from the 2000 estimate of 5.14 million tons. This level of decline was expected given the estimated age-structure of the population relative to availability patterns of pollock to the bottom-trawl survey. For the echo-integration trawl (EIT) surveys we used an updated estimate of abundance-at-age from the 2000 summer survey and also used revised sample-size values for the time series of EIT abundance-at-age data that reflects the number of trawl-hauls.

The NMFS observer samples of pollock age and size composition were evaluated for the 2000 fishery and these data were included in the analyses. The estimates of average weight-at-age from the fishery were also revised. The total catch estimate was updated for 2000 and for 2001, we assumed that the catch is equal to the 2001 TAC (1,400,000 t). We also examined observer data for different fishing patterns with the implementation of recent management measures.

Changes in the assessment model
Minor changes to the assessment model were made relative to that used in Ianelli et al. (2000). These include adding an environmental effect (bottom temperatures) to survey catchability and developing alternative specifications for selectivity forms for the fisheries and surveys (following recommendations from the NPFMC's SSC).

Changes in the assessment results
Alternative stock assessment model configurations all indicated somewhat higher overall abundance levels than those estimated from last year's model. For example, the 2000 biomass level as estimated from this year's model is 12% higher than the estimate from last year's assessment model. This highlights that estimates from the assessment models are always highly uncertain (confidence bounds ranging from half to double the point estimates are not uncommon, particularly for stocks that are on or near an increasing trend).

Computations leading to the year 2002 maximum ABC alternatives based on the $F_{40\%}$ and F_{msy} are 2,269 and 2,108 thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value). The lower value for the F_{msy} value this year reflects the level of uncertainty about stock size. The 2002 overfishing level (OFL) alternatives for the reference model are 2,833 and 3,531 thousand tons corresponding to $F_{35\%}$ and F_{msy} (arithmetic mean). These harvest level determinations fail to account for uncertainty in potential changes in harvest rates on the EBS stock outside of the US EEZ (particularly for pre-recruit age groups). Also, apparent continuing declines in Steller sea lion populations in adjacent areas continue to cause concern since pollock are an important prey item. Stock levels appear to be quite high for EBS pollock, but a large degree of uncertainty in the estimates remain. We therefore feel that quotas below these ABC levels would obviously be prudent. For example, a fixed catch of 1.4 million tons is projected to maintain the stock above the $B_{40\%}$ level of spawning stock biomass in the near term.

In the summer of 2000, NMFS conducted a bottom-trawl survey throughout the Aleutian Islands region. The estimate of on-bottom pollock in the Aleutians from this survey is 105,554 t. This gives **ABC** and **OFL values of 23,750 t** and **31,666 t,** respectively.

For the Bogoslof region, we followed the SSC recommendations and compute maximum permissible ABC and OFL based on Tier 5. This results in **34,800 t** and **46,400 t** for ABC and OFL, respectively. Further to the December 1999 SSC meeting minutes; we reduced the ABC relative to the target stock size (2 million tons). This gives a recommended 2002 ABC of **4,310 t** for the Bogoslof Island region.

1.1. Introduction

The stock structure of Bering Sea pollock (*Theragra chalcogramma*) is not well defined. In the U.S. portion of the Bering Sea pollock are considered to form three stocks for management purposes. These are: eastern Bering Sea which consists of pollock occurring on the eastern Bering Sea shelf from Unimak Pass and to the U.S.-Russia Convention line; Aleutian Islands Region which encompasses the Aleutian Islands shelf region from 170°W to the U.S.-Russia Convention line; and Central Bering Sea -Bogoslof Island pollock, which are thought be a mixture of pollock that migrate from the U.S. and Russian shelves to the Aleutian Basin around the time of maturity. In the Russian EEZ, pollock are considered to form two stocks, a western Bering Sea stock centered in the Gulf of Olyutorski, and a northern stock located along the Navarin shelf from 171°E to the U.S.- Russia Convention line. The northern stock is believed to be a mixture of eastern and western Bering Sea pollock with the former predominant. Currently, scientists at the AFSC are collaborating on a genetics study that will help clarify issues surrounding stock structure. In September 1999, scientists from countries belonging to the Central Bering Sea Convention convened a stock identification workshop in Yokohama, Japan, where they presented results of current research on pollock stock identification. This workshop addressed the current state-of-the-art techniques. A sampling protocol and exchange program between the countries was established. Problems were highlighted and efforts were made to keep management applications of stock-structure studies a high priority.

1.2. Catch history and fishery data

From 1954 to 1963, pollock were harvested at low levels in the Eastern Bering Sea and directed foreign fisheries began in 1964. Catches increased rapidly during the late 1960s and reached a peak in 1970-75 when catches ranged from 1.3 to 1.9 million t annually (Fig. 1.1). Following a peak catch of 1.9 million t in 1972, catches were reduced through bilateral agreements with Japan and the USSR.

Since the advent of the U.S. EEZ in 1977 the annual average eastern Bering Sea pollock catch has been 1.2 million t and has ranged from 0.9 million in 1987 to nearly 1.5 million t (including the Bogoslof Islands area catch; Fig. 1.1) in 1990 while stock biomass has ranged from a low of 4-5 million to highs of

10-12 million t. In 1980 United States vessels began fishing for pollock and by 1987 they were able to take 99% of the quota. Since 1988, only U.S. vessels have been operating in this fishery and by 1991, the current domestic observer program of this fishery was fully operational.

Foreign vessels began fishing in the mid-1980s in the international zone of the Bering Sea (commonly referred to as the "Donut Hole"). The Donut Hole is entirely contained in the deep water of the Aleutian Basin and is distinct from the customary areas of pollock fisheries, namely the continental shelves and slopes. Japanese scientists began reporting the presence of large quantities of pollock in the Aleutian Basin in the mid-to-late 1970's, but large scale fisheries did not occur until the mid-1980's. In 1984, the Donut Hole catch was only 181 thousand t (Fig. 1.1, Table 1.1). The catch grew rapidly and by 1987 the high seas catch exceeded the pollock catch within the U.S. Bering Sea EEZ. The extra-EEZ catch peaked in 1989 at 1.45 million t and has declined sharply since then. By 1991 the donut hole catch was 80% less than the peak catch, and data for 1992 and 1993 indicate very low catches (Table 1.1). A fishing moratorium was enacted in 1993 and only trace amounts of pollock have been harvested from the Aleutian Basin by resource assessment fisheries.

1.2.1. Fishery characteristics

The pattern of the fishery from 1995 to 1999 had been to have an "A-season" opening on January 20th with the season lasting about 1 month, depending on the catch rate. Historically, a second "B-season" opening has occurred on September 1st (though 1995 opened on Aug 15th). This has changed considerably over the past few years and management has focused on minimizing the possibility that the pollock fishery inhibits the recovery of the Steller sea lion population or adversely modifies their habitat. We discuss this in detail in the next section.

Since the closure of the Bogoslof management district (518) to directed pollock fishing in 1992, the "A-season" (January – March) pollock fishery on the eastern Bering Sea (EBS) shelf has been concentrated primarily north and west of Unimak Island (Ianelli *et al.* 1998). Depending on ice conditions and fish distribution, there has also been effort along the 100 m contour between Unimak Island and the Pribilof Islands. This pattern has gradually changed during the period 1999 - 2001 (Fig. 1.2). The total catch estimates by sex for the A-season compared to the fishery as a whole indicates that over time, the number of males and females has been fairly equal with a slight tendency to harvesting males more than females in recent years (Fig. 1.3). The length frequency information from the fishery shows that the size of pollock is generally larger than 40 cm but with some smaller fish caught during years when a strong year-class appeared (Fig. 1.4).

After 1992, the "B-season" (typically September – October) fishery has been conducted to a much greater extent west of 170°W than it had been prior to 1992 (Ianelli *et al.* 1998). This shift was due to the implementation of the CVOA (Catcher Vessel Operational Area) in 1992 and also the geographic distribution of pollock by size. The pattern in the past few years shows an increase in this trend (towards catching pollock west of 170°W) and decreasing amounts with the Sea lion conservation area (SCA) until this year. Large removals occurred within the SCA in the second half of 2001 compared to 1999 and 2000 (Fig. 1.5).

The length frequency information from the fishery reveals a marked progression of the large 1989 year-class growing over time and the appearance of the 1992 year-class in 1996-97 and subsequent 1996 year class in 1998-2001 (Fig. 1.6).

1.2.2. Fisheries Management

In response to continuing concerns over the possible impacts groundfish fisheries may have on rebuilding populations of Steller sea lions, NMFS and the NPFMC have made changes to the Atka mackerel (mackerel) and pollock fisheries in the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA). These have been designed to reduce the possibility of of competitive interactions with Steller sea lions. For the pollock fisheries, comparisons of seasonal fishery catch and pollock biomass distributions (from surveys) by area in the eastern Bering Sea (EBS) led to the conclusion that the pollock fishery had disproportionately high seasonal harvest rates within critical habitat which *could* lead to reduced sea lion prey densities. Consequently, the management measures were designed to redistribute the fishery both temporally and spatially according to pollock biomass distributions. The underlying assumption in this approach was that the independently derived area-wide and annual exploitation rate for pollock would not reduce local prey densities for sea lions. Here we examine the temporal and spatial dispersion of the fishery to evaluate the potential effectiveness of the measures.

Three types of measures were implemented in the pollock fisheries:

- Additional pollock fishery exclusion zones around sea lion rookery or haulout sites,
- Phased-in reductions in the seasonal proportions of TAC that can be taken from critical habitat, and
- Additional seasonal TAC releases to disperse the fishery in time.

Prior to the management measures, the pollock fishery occurred in each of the three major fishery management regions of the north Pacific ocean managed by the NPFMC: the Aleutian Islands (1,001,780 km^2 inside the EEZ), the eastern Bering Sea (968,600 km^2), and the Gulf of Alaska (1,156,100 km^2). The marine portion of Steller sea lion critical habitat in Alaska west of 150°W encompasses 386,770 km^2 of ocean surface, or 12% of the fishery management regions.

Prior to 1999, a total of 84,100 km^2, or 22% of critical habitat, was closed to the pollock fishery. Most of this closure consisted of the 10 and 20 nm radius all-trawl fishery exclusion zones around sea lion rookeries (48,920 km^2 or 13% of critical habitat). The remainder was largely management area 518 (35,180 km^2, or 9% of critical habitat) which was closed pursuant to an international agreement to protect spawning stocks of central Bering Sea pollock.

In 1999, an additional 83,080 km^2 (21%) of critical habitat in the Aleutian Islands was closed to pollock fishing along with 43,170 km^2 (11%) around sea lion haulouts in the GOA and eastern Bering Sea. Consequently, a total of 210,350 km^2 (54%) of critical habitat was closed to the pollock fishery. The portion of critical habitat that remained open to the pollock fishery consisted primarily of the area between 10 and 20 nm from rookeries and haulouts in the GOA and parts of the eastern Bering Sea foraging area.

The Bering Sea/Aleutian Islands pollock fishery was also subject to changes in total catch and catch distribution. Disentangling the specific changes in the temporal and spatial dispersion of the EBS pollock fishery resulting from the sea lion management measures from those resulting from implementation of the American Fisheries Act (AFA) is difficult. The AFA reduced the capacity of the catcher/processor fleet and permitted the formation of cooperatives in each industry sector by 2000. Both of these changes would be expected to reduce the rate at which the catcher processor sector (allocated 36% of the EBS pollock TAC) caught pollock beginning in 1999, and the fleet as a whole in 2000. Because of some of its provisions, the AFA gave the industry the ability to respond efficiently to changes mandated for sea lion conservation that otherwise could have been more disruptive to the industry.

Reductions in seasonal pollock catches from BSAI sea lion critical habitat were realized by closing the entire Aleutian Islands region to pollock fishing and by phased-in reductions in the proportions of seasonal

TAC that could be caught from the Sea Lion Conservation Area, an area which overlaps considerably with sea lion critical habitat. In 1998, over 22,000 mt of pollock was caught in the Aleutian Island regions, with over 17,000 mt caught in AI critical habitat. Since that time directed fishery removals of pollock have been prohibited.

On the eastern Bering Sea shelf, both the catches of pollock and the proportion of the total catch caught in critical habitat have been reduced significantly since 1998 as a result of the management measures (though the drop in the latter half of 2000 was due to closures from an injunction):

Year	Months	Catch Outside SCA	Total Catch	Percent Inside SCA
1998	Jan-Jun	70,786	384,899	82%
	Jun-Dec	247,691	403,068	39%
	Jan-Dec	318,477	787,967	60%
1999	Jan-Jun	154,963	338,801	54%
	Jun-Dec	360,117	467,776	23%
	Jan-Dec	515,080	806,577	36%
2000	Jan-Jun	240,801	375,285	36%
	Jun-Dec	550,109	571,903	4%
	Jan-Dec	790,910	947,188	16%
2001	Jan-Jun	343,458	474,545	28%
	Jun-Dec	367,686	641,660	43%
	Jan-Dec	711,144	1,116,205	36%

Note: Pollock catches as reported by at-sea observers only, 2001 data are preliminary.

An additional goal for minimizing the potential for impacting the sea lion population is to disperse the fishery throughout more of the pollock range on the eastern Bering Sea shelf. This was apparent in the first half of 2001 with more fishing distributed northwest of the SCA and around the Pribolof Islands (Fig. 1.2). However, in the second-half of 2001 the fishery was more concentrated than usual within the SCA (Fig. 1.5). This is in sharp contrast to the same period in 2000 when this area was closed for much of the season.

Seasonal TAC releases were intended to disperse the fishery throughout more of the year. Prior to the increased sea lion conservation measures, the fishery was concentrated in 2 seasons, each approximately 6 weeks in length in January-February, and September-October; 94% of the pollock fishery occurred during these four months, with 45% in January-February and 49% in September-October. In 1999, the measures dispersed the early fishery into March (which reduced the percentage taken in February) and the later fishery into August, but very little into the April-July period. One way of examining the seasonal aspect of the 2000 fishery is to plot the raw observer sampling effort by month (Fig. 1.7). This is roughly proportional to total catch by the pollock fishery and shows that significant removals occurred in 7 months of the year.

Also relevant to current management measures are examinations of historical patterns of pollock fishing. For this we compiled foreign observer data by month for each year and computed the geographic center of where the removals occurred. Results show that the fishing patterns in the 1980s were quite different than in the 1990s. There appears to be much greater separation between fishing in the early and later seasons within a year during the 1990s while during the 1980s, there appears to be very similar centers of catch distributions in both early and late seasons (Fig. 1.8). This could be partly due to differences in observer coverage and changes to pelagic gear during the 1990s.

1.2.3. Catch data

Significant quantities of pollock are discarded and must be taken into account in estimation of population size and forecasts of yield. Observer length frequency observations indicated that discarded pollock include both large and small pollock. Since observers usually sample the catch prior to discarding, the size distribution of pollock sampled closely reflects that of the actual *total* catch. Discard data as compiled by the NMFS Alaska Regional Office have been included in estimates of total catch since 1990.

Pollock catch in the eastern Bering Sea and Aleutian Islands by area from observer estimates of retained and discarded catch, 1990-2000 are shown in Table 1.2. Since 1990 estimates of discarded pollock have ranged from a high of 11% of total pollock catch in 1991 to a low of 1.5% in 1998 (the 2000 value was 2%). These recent low values reflect the implementation of the Council's Improved Utilization and Improved Retention program. Variability in discard rates may also be due to the age-structure and relative abundance of the available population. For example, if the most abundant year-class in the population is below marketable size, these smaller fish may be caught incidentally. With the implementation of the AFA, the fleets have more time to pursue the sizes of fish they desire since they are guaranteed a fraction of the quota. In addition, several vessels have made gear modifications to avoid retention of smaller pollock. In all cases, the magnitude of discards is accounted for within the population assessment and for management (to ensure the TAC is not exceeded).

We estimate the catch-at-age composition using the methods described by Kimura (1989) and modified by Dorn (1992). Briefly, length-stratified age data are used to construct age-length keys for each stratum and sex. These keys are then applied to randomly sampled catch length frequency data. The stratum-specific age composition estimates are then weighted by the catch within each stratum to arrive at an overall age composition for each year. Data were collected through shore-side sampling and at-sea observers. The three strata for the EBS were: 1) INPFC area 51 from January - June; 2) INPFC area 51 from July - December; and 3) INPFC area 52 from January - December. This method was used to derive the age compositions from 1991-2000 (the period for which all the necessary information is readily available). Prior to 1991, we used the same catch - age composition estimates as presented in Wespestad *et al.* (1996). Recently, we examined stratifying the fisheries catch data by month and NMFS survey areas as opposed to the normal fishery seasons and INPFC areas. The results from this work are preliminary but compared favorably with the current estimates of catch-at-age.

The time series of the catch proportions-at-age suggests that in 1999 and 2000 a broad range of age groups were harvested with a continued strong showing of the 1992, 1995, and 1996 year classes (Fig. 1.9). We present these values (as used in the age-structured model) from 1979-2000 in Table 1.3. The 1999 and 2000 estimates of pollock catch-at-age data were collected using a new survey sampling strategy. Under the new scheme, more observers collect otoliths from a greater number of hauls (but far fewer specimens per haul). The objective of the new system was to improve geographic coverage while at the same time lowering the total number of otoliths collected (since a large number were not subsequently aged and arguably would not contribute further to the precision of catch-at-age estimates). The geographic coverage was significantly improved (Fig. 1.10) as was the precision when compared with earlier years (Fig. 1.11). The sampling effort for lengths was significantly decreased in 1999 and 2000, but the number of otoliths processed for age-determinations increased (Table 1.4). As part of a study to evaluate the effectiveness of the new sampling protocol, observers in 1999 also collected data using the "old" method. These samples have not been processed to date but should allow a more direct comparison between the old and new methods.

1.3. Resource surveys

This year, scientific research catches are reported to fulfill requirements of the Magnuson-Stevens Fisheries Conservation and Management Act. The following table documents annual research catches (1977 - 1999) from NMFS surveys in the Bering Sea and Aleutian Islands Region (tons):

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Bering Sea	15	94	458	139	466	682	508	208	435	163	174	467
Aleutian Is.				193		40	454			292		

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Bering Sea	393	369	465	156	221	267	249	206	262	121	162	NA	NA
Aleutian Is.			51			48			36			NA	NA

Since these values represent extremely small fractions of the total removals (~0.02%), they are not explicitly added to the total removals by the fishery.

1.3.1. Bottom trawl surveys

Trawl surveys have been conducted annually by the AFSC to assess the abundance of crab and groundfish in the Eastern Bering Sea. Until 1975 the survey only covered a small portion of the pollock range. In 1975 and since 1979, the survey was expanded to encompass more of the EBS shelf occupied by pollock. The level of sampling for lengths and ages in the bottom-trawl survey is shown in Table 1.5.

Since 1983 the biomass estimates have been relatively high and showed an increasing trend through 1990 (Table 1.6). Between 1991 and 2001 the bottom trawl survey biomass estimate has ranged from 2.2 to 5.5 million t. The estimate for 2001 is 4.14 million tons, down 19.5% from the 2000 estimate of 5.14 million. In general, the survey indicates a relatively stable stock trend since 1982 with periods of 3-4 years of increases and decreases (Fig. 1.12). This variability is due to the effect of year-class variability evident from survey abundance-at-age estimates (Fig. 1.13). One characteristic of year class variability from survey data is that some strong year-classes appear in the surveys over several ages (e.g., the 1989 year class) while others appear at older ages (e.g., the 1992 year class). This suggests that the age-specific spatial distribution of pollock available to bottom-trawl gear is variable.

In 2001, pollock catch-rates were slightly higher than usual around St. Matthew Island with other pockets of high densities in the northwest region, west of the Pribolof Islands, and just northeast of Unimak Island (Fig. 1.14). The survey age composition information also provides insights on patterns in length-at-age. In particular, when converted to weights-at-age it appears that in recent years the average size (ages 4-8) is about 90% of the average since 1982. (Fig. 1.15). Since 1982, the pattern in size at age shows a regular periodic trend about every 10 years.

As in the past few assessments, we conducted an analysis on the total mortality of the 1974-1992 cohorts based solely on NMFS survey data. This simple approach involves regressing the log-abundance of age 6 and older pollock against age by cohort. We selected age 6 because younger pollock are still recruiting to the bottom trawl survey gear. A key assumption of this analysis is that all ages are equally available to the gear. The estimates of total mortality by cohort are difficult to interpret—here we take them as some form of average mortality over the life of the cohort (since we know that harvest rates varied from year to year). The values used in the regression are shown in Fig. 1.16. The estimates of mortality shows somewhat of an increasing trend for these cohorts with a mean total instantaneous value around 0.45 (except for the 1990-1992 cohorts; Fig. 1.17). The low values estimated from some year-classes, namely the 1990-1992 cohorts, could be due to the fact that there are fewer age-groups (6, 5, and 4, respectively) in the regressions. Alternatively, it may suggest some net immigration into the survey area or a period of lower natural mortality. In general, these values are consistent with the types of values obtained from within the assessment models for total mortality (though the model values tend to be somewhat higher, averaging about 0.5 for these cohorts).

Studies on the spatial abundance by area

Research on applying NMFS survey data to gain insights on the movement and distribution of pollock around the Bering Sea continues. Recently, survey catch rates have been compiled on an age-specific basis. This facilitates comparing catch rates by age over space and time. One application of such analyses is to examine the relative abundance inside and outside of management areas. For example, catch rates inside of the Sea lion conservation area shows the tendency for few young fish and relatively high old-fish catch rates compared to pollock outside of the SCA (Fig. 1.18). This gives some indication of how selectivity/availability of the age-structured population may change under different geographical management practices.

In addition to evaluating the overall geographic concentrations of pollock over time, these data were further broken down by length and ages. Compared to the average CPUE-weighted mean length distribution by area, the 2001 survey had bigger pollock in the shallow areas of Bristol Bay and around Nunivak Island and a swath of pollock 30-35 cm mean length in the middle shelf region (Fig. 1.19).

These mean-length patterns show that in general, smaller fish are more common in the northern areas with apparent movement towards the south and east as the pollock become larger. These patterns are also revealed when one computes the centers of abundance based on age-specific CPUE data. This is done by simply computing the CPUE-weighted average location for specific ages. Since bottom temperature has long been considered important in the distribution of pollock on the shelf, we pooled over years into three categories: cold (°C < 2), intermediate ($2 \leq$ °C < 3), and warm (°C ≥ 3) based on the mean bottom temperature (Fig. 1.20). The average locations for warm years are further on-shelf than for cold years (Fig. 1.21) indicating a broader dispersal onto the shelf in warmer years. The average locations for intermediate years were not depicted here, but were most similar to the cold years. The mean centers of distribution in both warm and cold years have very similar patterns with age. Younger fish are found to the north and northwestern regions and as they age, the centers of distribution move south and southeasterly. Similar evaluations (Buckley et al. In Prep.) show that among the strong year-classes, centers of distribution tend to be either “northwest” type or “southeast” type (Fig. 1.22). They show a number of possible factors contributing to these patterns including density dependence and early-life conditions.

Effect of temperature

This year we introduced use of the bottom temperature data collected during the NMFS summer bottom-trawl surveys. Since we have shown that temperature affects the distribution of pollock on the shelf, it seems likely that temperature may affect the availability of the stock to the survey. That is, temperature may affect the proportion of the stock that is within or outside of the standard survey area. We therefore evaluate this potential as an effect on the survey catchability in year *t* base on temperature T_t as:

$$q_t = \mu_q + \beta_q T_t$$

where μ_q is the mean catchability and β_q represents the slope parameter. The time series of temperature (Fig. 1.20) is used in Model 4 (which, for the model was normalized to have a mean value of zero).

1.3.2. Echo-integration trawl (EIT) surveys

Whereas bottom trawl surveys are conducted annually and assess pollock from the bottom to 3 m off bottom, EIT surveys have been conducted approximately triennially since 1979 to estimate pollock in midwater (Traynor and Nelson 1985). However, during the last decade 6 EIT summer surveys have been conducted in 1991, 1994, 1996, 1997, 1999 and 2000. The details and research results from these EIT surveys have been presented in detail in previous assessments (e.g., Ianelli et al. 2000; Honkalehto et al. In Prep.).

Proportions of pollock biomass estimated east vs. west of 170º W, and inside vs. outside the sea lion conservation area (SCA), are about the same for summer EIT surveys conducted from 1994 to 2000 (Table 1.7). The time series of estimated EIT survey proportions-at-age is presented in Fig. 1.23. The number of trawl-hauls, and sampling quantities for lengths and ages from the EIT survey are presented in Table 1.8. Otolith age-determinations from the 2000 EIT survey were completed in the last year and have been incorporated in this assessment. The difference from the numbers-at-age used in selected model configurations in Ianelli et al. (2000) is shown in Fig. 1.24.

In 2000 and 2001 NMFS conducted winter EIT surveys on the EBS shelf region in addition to the Bogoslof Island region. These added areas cover most of the SCA. Details of the 2001 research is presented in an Appendix report in this volume. One purpose of these studies is to assess the variability of pollock concentrated within this zone by season and over different years. Preliminary analyses piecing these data together with the main assessment model have provided some indication that the population tends to aggregate within the SCA in the winter. Unfortunately, the estimated "available" segment of the population (based on age compositions from 1991, 1995, 2000, and 2001 surveys) suggests that a broad range of ages are either within the shelf area but not fully vulnerable to the trawl or echo sign (e.g., the fish could be on the bottom and hence not counted in the echo-integration procedure); or outside of the area (Fig. 1.25). Unfortunately, the relative degree of vulnerability/availability is difficult to quantify. Presumably, younger fish tended to be outside of this region during the winter (since they are commonly found/caught during summer EIT surveys) while older bigger fish may be in the area but close to the bottom (as indicated from bottom trawl surveys).

1.4. Analytic approach

1.4.1. Model structure

The SAM analysis was first introduced in the 1996 SAFE (Ianelli 1996) and was compared with the cohort-analysis method that has been used extensively for pollock in past years. Since the cohort-analyses methods can be thought of as special cases of the SAM analysis (e.g., as shown in Ianelli 1997), we have not continued the use of VPA/cohort algorithms due to their limitations in dealing with many aspects of data in a statistical sense. The statistical age-structured approach has also been documented from analyses performed on simulated data for the Academy of Sciences National Research Council (Ianelli and Fournier 1998). Other changes from last year's analyses include:

- Investigations on the spatial distribution of pollock by age was pursued
- Based on spatial distribution results, an environmental time series (bottom temperatures) were added to the model as a potential effect on stock availability to bottom trawl survey gear
- The 2001 EBS bottom trawl survey estimate of population numbers-at-age was included.
- The 2000 EBS EIT survey estimate of population numbers-at-age were updated from the preliminary values used in last year's assessment.
- Investigations on alternative specifications for selectivity forms for the fisheries and surveys were pursued (following recommendations from the NPFMC's SSC).

The technical aspects of this model are presented in Section 1.14 and have been presented previously (Ianelli 1996, and Ianelli and Fournier 1998). Briefly, the model structure is developed following Fournier and Archibald's (1982) methods, with a number of similarities to Methot's extension (1990). We implemented the model using automatic differentiation software developed as a set of libraries under C++.

1.4.2. Parameters estimated independently

Natural Mortality and maturity at age

We assumed fixed natural mortality-at-age values based on studies of Wespestad and Terry (1984). These provide estimates of M=0.9, 0.45, and 0.3 for ages 1, 2, and 3+ respectively. These values have been used since 1982 in catch-age models and forecasts and appear to approximate the true rate of natural mortality for pollock. Recent studies on Gulf of Alaska pollock indicate that natural mortality may be considerably higher when predators are taken explicitly into account. This may also hold for the EBS region, however, the abundance of pollock is proportionately much higher than all other fish species compared to the Gulf of Alaska. This may explain why cannibalism is much more common in the EBS than in the Gulf. Note that to some degree, the role of cannibalism is modeled through the implementation of a Ricker (1975) stock-recruitment curve. This curve can take the form where having higher stock sizes may result in lower average recruitment levels.

Maturity at age was assumed the same as that given in Wespestad (1995) which dates back to Smith (1981). This was shown to be consistent with maturity observed in winter surveys in recent years. However, this research is continuing and will be an active study area to coincide with future winter surveys and observer data collections. These values are given here together with the baseline assumption of natural mortality-at-age:

Age	1	2	3	4	5	6	7	
M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	
Prop. Mature	0.000	0.008	0.290	0.642	0.842	0.902	0.948	
Age	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
M	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Prop. Mature	0.964	0.970	1.000	1.000	1.000	1.000	1.000	1.000

Length and Weight at Age

Length, weight, and age data have been collected extensively for pollock. Samples of length-age and weight-length data within each stratum indicate growth differences by sex, area, and year-class. General patterns have been that pollock in the northwest area are slightly smaller at age than in the southeast. Since our estimates of harvests-at-age are stratified by area (and season), these differences are taken into account before analyses within the model. For the fishery, we use year (when available) and age-specific estimates of average weights-at-age as computed from the fishery age and length sampling programs. These values are shown in Table 1.9 and are important for converting model estimated catch-at-age (in numbers) to estimated total annual harvests (by weight). Since we do not assume a fishery catch-effort relationship explicitly, the fishing mortality rates depend largely on the total annual harvests by weight. For the bottom-trawl and EIT surveys, we tune the model to estimates of total numbers of fish.

1.4.3. Parameters estimated conditionally

For the reference model presented here, 723 parameters were estimated. These include vectors describing recruitment variability in the first year (as ages 2-15 in 1964) and the recruitment deviations (at age 1) from

1964-2001. Additionally, projected recruitment variability was also estimated (using the variance of past recruitments) for five years (2002-2006). The two-parameter stock-recruitment curve is included in addition to a term that allows the average recruitment before 1964 (that comprises the initial age composition in that year) to have a mean value different from subsequent years. Thus, 61 parameters comprise initial age composition and subsequent recruitment values.

Fishing mortality is parameterized to be semi-separable. That is, there is a year component and an age (selectivity) component. The age component is allowed to vary over time with changes allowed every three years. The age component is constrained such that its mean value will be equal to one, this means that it will not be confounded with the time component (see Section 1.14, Model details). In addition, we assume that the age-component parameters are constant for the last 4 age groups (ages 12-15). Therefore, the time component of fishing mortality numbers 38 parameters (estimable since we place low variance on the likelihood component on the total catch biomass) and the added age-time component of variability results in a 12x12 matrix of 144 parameters. This brings the total fishing mortality parameters to 192. Please note however, that in standard cohort analyses such as that of Pope (1972) the number of parameters for a similarly dimensioned problem would be 38x15 or 570 fishing mortality parameters. Of course in a VPA, these parameters are not estimated statistically, rather implicitly using an algorithm that assumes no errors in the total catch-at-age.

For the bottom trawl survey, a similar parameterization for the selectivity-at-age estimates includes an overall catchability coefficient, age and year specific deviations in the average availability-at-age which totals 215 parameters for these data. Similarly, for the EIT survey, which began in 1979, these parameters number 233. Estimates for changes in EIT selectivity sometimes occur for years when the survey was not conducted. This increases the number of parameters we estimate, but avoids problems associated with surveys occurring on irregularly spaced intervals. The idea of estimating these changes is to allow some continuity in unaccounted-for variability of fish available to our survey gear. That is, we expect things to change in this regard but our null hypothesis is that the survey operation is constant with respect to relative changes in age class availability.

Finally, 2 additional fishing mortality rates are estimated conditionally. These are the values corresponding to the $F_{40\%}$ and $F_{35\%}$ harvest rates. These rates satisfy the constraint that given selectivity-at-age vector (we used the mean selectivities based on model configuration), proportion-mature-at-age, natural mortality rate, and weight at age, there are unique values that correspond to the fishing mortality rates.

The likelihood components can thus be partitioned into the following groups:

- Total catch biomass (Log normal, σ=0.05)
- Bottom trawl survey variances (annual estimates of standard error, as represented in Fig. 1.12) and an assumed variance for the EIT survey abundance index, (i.e., Log normal, σ=0.2)
- Fishery and survey proportions-at-age estimates (Robust quasi-multinomial with effective sample sizes presented in Table 1.10). These values were selected based on comparisons of catch-at-age variance estimates obtained from the fishery stratified sampling scheme (Kimura 1989) with values obtained in earlier fits to the stock assessment model (Ianelli 1996, Table A1, Annex B).
- Selectivity constraints (penalties on age-age variability, time changes, and decreasing (with age) patterns)

1.5. Model evaluation

To examine model assumptions and data sensitivities, we evaluated several dozen different model configurations. For clarity, we present a limited number of these results. Some of these are in response to specific requests by the NPFMC family and others are intended to illustrate some properties of model behavior relative to the extensive surveys and fishery observations conducted by the AFSC for walleye pollock.

A list of the models presented includes:

Model 1 **Reference model,** future selectivity based on most recent (3-year) estimate (short-term selectivity estimate). This was the model configuration selected by the Council for ABC recommendations since 1998 with a slight modification to how we treat bottom-trawl survey selectivity (here as an asymptotic, time-varying logistic curve).

Model 2 As reference model but with bottom-trawl survey selectivities modeled as coefficients varying over time (and possibly decreasing with age).

Model 3 As reference model but with fishery selectivity allowed to change more frequently over time (SSC recommended sensitivity).

Model 4 As reference model but with bottom-trawl survey catchability including an environmental covariate (bottom temperature).

Model 5 As reference model, but with bottom-trawl survey catchability fixed at 1.0.

Model 6 As Model 5 but estimating natural mortality.

Model 7 As Reference Model, but disregarding the survey information.

These models can be summarized as follows:

Model	Description
1	Reference model
2	BTS selectivity as last year (2000 assessment)
3	Fishery selectivity allowed to vary more frequently
4	Bottom temperature a covariate with survey catchability
5	Bottom-trawl survey catchability fixed at 1.0.
6	Estimate natural mortality
7	Disregard all survey data

Our reference model can be characterized as one that includes a moderate number of stochastic processes. These are principally changes in age-specific availability over time for survey and fishery gears and recruitment variability. As specified, these processes involve a large number of parameters but capture a reasonable amount of the overall uncertainty. The slight change in reference model this year was to invoke a simplifying process on bottom-trawl survey catchability to have it be asymptotic yet retain the properties desired for the characteristics of this gear. Namely, that the function should allow for flexibility in selecting age 1 pollock. Additionally, time-varying shifts should be allowed. The new functional form of this selectivity is:

$$
\begin{aligned}
s_{t,a} &= \left[1 + e^{-\alpha_t(a-\beta_t)}\right]^{-1}, \; a > 1 \\
s_{t,a} &= \mu_s e^{\delta_t^\mu}, \qquad\qquad a = 1 \\
\alpha_t &= \bar{\alpha} e^{\delta_t^\alpha} \\
\beta_t &= \bar{\beta} e^{\delta_t^\beta}
\end{aligned}
$$

where the parameters of the selectivity function follow a random walk process as in Dorn et al. (2000):

$$
\begin{aligned}
\delta_t^\mu - \delta_{t+1}^\mu &\sim N\left(0, \sigma_{\delta^\mu}^2\right) \\
\delta_t^\alpha - \delta_{t+1}^\alpha &\sim N\left(0, \sigma_{\delta^\alpha}^2\right). \\
\delta_t^\beta - \delta_{t+1}^\beta &\sim N\left(0, \sigma_{\delta^\beta}^2\right)
\end{aligned}
$$

The parameters to be estimated in this part of the model are thus the $\bar{\alpha}, \bar{\beta}, \delta_t^\mu, \delta_t^\alpha, \text{and } \delta_t^\beta$ for t=1982, 1983,…2001. The variance terms for these parameters were specified to be 0.04.

Comparing this result with that used in the 2000 assessment (e.g., Model 2) gives an improved goodness of fit (i.e., a lower –ln(likelihood) function; Table 1.11). Also, the stock condition estimates from Model 1 are slightly less optimistic compared to Model 2 (Table 1.12). We prefer the new selectivity form for the bottom-trawl survey because asymptotic selectivity seems most appropriate for this gear type, particularly given that pollock tend to reside more on the bottom as they age.

As with last year, the stock-recruitment curve fitting for the Reference model (Model 1) is using only the period from 1978-2001. Also as with last year we ran models with many stock-recruitment alternatives (including: Beverton-Holt, constant recruitment, different assumptions about specified priors on steepness, length of time series used for estimating stock-recruitment relationship etc). Several of these alternative model specifications were presented in Ianelli et al. (2000) and all gave more optimistic scenarios than the Reference Model presented here.

In 2000, the Council's SSC requested that we examine alternatives where selectivity was allowed to vary more frequently over time. We first examined implementing a time-varying 4-parameter logistic function (with several alternative parameterizations). Our experience here was that the estimation became unstable. The reason we think this occurred was due to the fact that as the parameters for the selectivity function approached an ascending-asymptotic form, the parameters describing the descending limb of the selectivity function no-longer had correct derivatives. Since the 4-parameter logistic is a non-differentiable function problems can arise when derivatives are automatically computed (regardless if they are estimated by finite-difference methods). As a fall-back, we allowed the coefficients to vary every two years as in Model 3 and also in every year (though we chose not to present these results since they were very similar). Results from this configuration improved the fit to the data while other stock indicators were very similar to the reference case. Either Models 1 or 3 probably represents the uncertainty in the fishery age-specific selection process equally well.

Since there is some indication that the geographical distribution of pollock as observed by bottom-trawl survey gear shifts depending on temperature, we introduced mean bottom temperature as having an effect on survey catchability (Model 4). Results suggest that there is a slight negative relationship between bottom temperatures and survey catchability (slope -0.631, with standard error 0.363). The significance of this fit is moderate, given this standard error, and there is improvement in the overall fit (Table 1.11). Based on this relationship, survey catchability tends to be lower at warmer temperatures and slightly higher at colder temperatures (Fig. 1.26). In other words, in cold years pollock appear to be more available to the survey gear than in warm years. For contrast, in Model 5 we constrained survey catchability to be exactly equal to 1. This resulted in a worse fit to the data and a much higher biomass estimate.

Obtaining model estimates of survey catchability that are greater than 1.0 may seem counterintuitive, given that we expect the bottom-trawl gear to be missing pollock that are up in the water column and outside of the survey area. We note that there is a significant age-component to this catchability and that the estimates are likely an artifact of model mis-specification rather than due to the effects of "herding" or other survey mechanism. For example, factoring the age-effect (selectivity) of the survey gear and considering the average biomass of pollock age 5 and older, the survey catchability is slightly less than 1.0. Considering age 3 and older pollock biomass, the average catchability by the survey is about 0.70. This effect is because young pollock are less available to bottom-trawl survey gear.

In Model 6 we evaluated the ability of our model to estimate natural mortality (with survey catchability fixed at a value of 1.0). The parameterization was specified for age-3 and older as Me^{ρ} where the estimate was (from $M=0.3$): $\hat{\rho}=0.095$ with a standard error of 0.088 (and $Me^{\rho}=0.33$). This suggests that given the current model specification, alternative estimates of natural mortality are similar.

Finally, in Model 7 we examined the influence of our survey data on assessment model results. Disregarding both survey indices and age composition data sets (the data were still physically included in the model, but were downweighted in the –ln(likelihood) function to 1/100th of their original emphasis. This model yielded results surprisingly similar to Model 1, but with greater uncertainty.

In the past few years we've included an analysis using an ocean current circulation model to aid in the estimation of year-class strengths for forecasting. We failed to update this analysis this year but have found that its implementation had relatively little impact on values critical for harvest management regulations. The environmental effect did not appear to shift or influence the underlying stock-recruitment relationship that was estimated (although it did help explain part of the inter-annual variability). Some results from oceanic conditions dating back to 1960's are presented in Section 1.8 below.

Based on the examinations of the alternative models presented here (and also over those that were run but not presented) we feel that our Model 1 is appropriate and encompasses a wide range of uncertainties about the stock status.

1.5.1. A note about survey estimates and model results

Questions often arise about how biomass estimates from different surveys relate to model results since they are typically quite different. For example, the "total age-3+ biomass" estimates for 2001 are over 11 million tons compared to the bottom-trawl survey biomass estimate of slightly more than 4.1 million tons. Such a difference can be attributed to three main factors: **weight** (averaged by age), **time** (within a year), and **selectivity/availability**. In more detail:

Weight: The NMFS fishery observer program collects large amounts of pollock average-weight-at-age data. These are considered very reliable and include measurements of individual body length and weight along with age-determination structures. The averages we compute are actually the catch-weighted average over the entire year and do not represent estimates of average weight-at-age on January 1st. We could change this convention to reflect more precisely what the value is, but then comparisons would become difficult over different assessment years. Perhaps more importantly, the survey mean weights-at-age (as applied in deriving survey biomass estimates) are quite different from those observed in the fishery and can have large implications on the biomass estimates presented (Fig. 1.27).

Time: By convention, we have always applied the estimated mean-weight-at-age observed from the fishery to *begin-year* numbers at age as estimated within the model. The effect of fishing and natural mortality can be substantial prior to when the survey occurs in mid-summer. When we model survey abundance, we account for this within-year mortality prior to fitting model predictions to the observed survey abundance data. This difference alone (using begin-year abundance versus mid-year) has a substantial impact on the presentation of age-3+ biomass estimates (even using the same average weight-at-age data; Fig. 1.28).

Selectivity: It has been understood for some time that the bottom-trawl surveys do not sample all ages within the pollock population equally well. For example, we know that age-2 pollock are relatively rare in the survey gear. This is presumably an availability problem (off bottom, outside of area, etc). For example, correcting for the age-specific availability of the bottom-trawl surveys, the abundance expands on average 6-fold. Relative to the stock assessment model results, this expansion suggests that the survey over-estimates the abundance relative to our model results (Fig. 1.29). This result is conditioned on the estimates of age-specific availability/selectivity. However, these are likely to be robust since the survey tends to track age classes quite well over time. Also note that for our main result presented below, we estimate the bottom-trawl survey catchability to be about 1.44 (indicating a conservative application).

1.6. Results

Several key results have been summarized in Tables 1.12 & 1.13. The difference in the current and projected age structure for Model 1 relative to the last year's assessment (2000) is shown in Fig. 1.30. This figure shows that the absolute numbers at age are estimated to be somewhat higher in the current assessment. The increases may be attributed to the increase in the 1999 and 2000 survey abundance estimates (the bottom trawl survey in these two years increased by 61% and then 44%) and positive signs from the 2000 fishery catch-at-age data. Also, the 2000 EIT age composition data (updated this year) includes higher estimates of the 1996 year-class. The 1992 year-class is estimated to be slightly higher than in the past, presumably due to the predominance of that year-class in the recent EBS bottom-trawl surveys and in the fishery (e.g., Fig. 1.35 below). The 1996 year class is still estimated to be quite strong and is slightly higher than last year's estimate. This is also true for the 1995 year class (which has grown in strength based on the bottom-trawl survey; e.g., Fig. 1.13).

The estimated Model 1 selectivity pattern changes over time to become slightly more dome-shaped during the 1990s (Fig. 1.31). This may have coincided with the move to pelagic-only trawl gear as larger (older) fish tend to be more bottom-oriented. Model 1 fits the fishery age-composition data quite well and strong year classes are clearly evident (Fig. 1.32). The fit to the early Japanese fishery CPUE data (Low and Ikeda, 1980) is consistent with the populations trends for this period (Fig. 1.33).

We specified that selectivity could vary slightly over time for both surveys. This was done to account for potential changes in fish distribution. For example, it seems reasonable to assume that the presence of 1-year-olds available to the bottom-trawl gear on the shelf might be variable, even when the abundance is the same (Fig. 1.34). The bottom trawl survey age composition data are somewhat inconsistent in 2000 and 2001. The abundance of the 1995 year class has apparently increased while the proportion of the 1996 year class in these years was lower than expected (Fig. 1.35). Since the 1996 year class is so important to the fishery in the near-term, this development requires close attention (even though the 1996 year class has consistently appeared strong in the EIT survey (see below) and is currently recruiting well into the fishery).

We also point out that the 1992 year class was not well observed by the bottom trawl survey as age 3, 4, and to some extent, 5-year old pollock.

The Model 1 fit and estimated selectivity for the EIT survey data show a dramatic change in selectivity pattern over time (Fig. 1.36). This may be due in part to changes in pollock distribution (as the overall densities changed and also to the fact that large numbers of 1 and 2-year old fish were apparent in the survey that year. Also, the number of hauls sampled has generally increased over time—presumably this affects the overall estimate of the age composition of pollock available to the survey. These patterns are also illustrated in the model fit to the EIT survey age composition data (Fig. 1.37). The proportions at age observed in the survey are generally consistent with what appeared later in the bottom-trawl survey and fishery. Estimated numbers-at-age for Model 1 are presented in Table 1.14 and estimated catch-at-age presented in Table 1.15.

Uncertainty computations are a central part of the analyses presented in this assessment. In the past year, development of Bayesian integration methods has continued. Often with highly non-linear models, the multidimensional shape of the posterior distribution can be highly curved and present problems when expressing approximations to marginal distributions (e.g., as we do here via the Delta-method propagation-of-errors to obtain variance estimates for management quantities of interest). To explore this property, we computed the joint distribution based on 1 million Monte-Carlo Markov Chain simulations drawn from the posterior distribution. The chain was thinned to reduce potential serial correlation to 5,000 parameter "draws" from the posterior distribution. Selected model parameters (Model 1) are plotted pair-wise to provide some indication of the shape of the posterior distribution. In general, the model given the available data appears to be quite well behaved (clusters of parameters do not appear to follow strange curved or skewed tear-drop shapes; Fig. 1.38). In terms of policy evaluation, we projected the model forward (for each "sample" from the posterior) with a fixed catch of 1.3 million tons. The probability that the current stock size is below the (uncertain) $B_{40\%}$ level is quite low. However, by 2003, the expectation is that the stock size will be close to the $B_{40\%}$ stock size level, then increase (with considerable uncertainty) to well above this level by 2006 (Fig. 1.39).

1.6.1. Abundance and exploitation trends

The eastern Bering Sea bottom trawl survey estimates exhibited an increasing trend during the 1980s, were relatively stable from 1991 to 1995, and decreased sharply in 1996 but rose slightly in 1997 and then substantially in 1999 and 2000. This may be due, in part, to age-related distribution changes within the pollock population. Results from combined bottom trawl and EIT surveys, which more fully sample the population, have shown that older pollock are more vulnerable to bottom trawls than younger pollock (e.g., Figs. 1.34 and 1.35).

Current "exploitable" biomass estimates (ages 3 and older) derived from the statistical catch-age model suggest that the abundance of eastern Bering Sea pollock remained at a fairly high level from 1982-88, with estimates ranging from 10 to 11.5 million t. Peak biomass occurred in 1985 and declined to about 5 million t by 1991. Since then, the stock has apparently increased, declined slightly then increased again and is currently estimated to be over 11 million tons[1].

Historically, biomass levels have increased from 1979 to the mid-1980's due to the strong 1978 and relatively strong 1982 and 1984 year-classes recruiting to the fishable population (Table 1.16, Fig. 1.40). From 1985-86 to 1991 the fishable stock declined as these above average year-classes decreased in abundance with age and were replaced by weaker year-classes. In 1992 an upturn in abundance began

[1] Please refer to section 1.5.1 for a discussion on the interpretation of age-3+ biomass estimates.

with the recruitment of a strong 1989 year-class and peaked around 1995. An increase in abundance is expected in future years as apparently above average 1996 year-class recruits to the exploitable population. Retrospectively, compared with last year's assessment the recent estimates of age 3+ pollock biomass are somewhat lower in the current assessment during the 1980s and higher in recent years (Table 1.16). Again, this may be attributed to the increasing trends from both the EIT and bottom trawl survey estimates for 1999. Overall, compared with seven past assessments, the retrospective pattern shows a steady increase in estimates of stock size during the late 1990s (Fig. 1.41).

The abundance and exploitation pattern estimated from Model 1 shows that the spawning exploitation rate (SER, defined as the percent removal of spawning-aged females in any given year) has averaged about 18% in the past 10 years (Fig. 1.42). This compares to an overall average SER of 22.5% (1964 – 2000). The observed variation in pollock abundance is primarily due to natural variation in the survival of individual year-classes. These values of SER are relatively low compared to the estimates at the MSY level (~30%).

1.6.2. Recruitment

Recruitment of pollock is highly variable and difficult to predict. It is becoming clear that there is a great deal of variation in the distribution of pre-recruit pollock, both in depth and geographic area. To some extent, our approach takes this into account since age 1 fish are included in our model and data from both the EIT and bottom trawl survey are used. In earlier assessments (prior to 1998), the primary measure of pollock recruitment has been the relative abundance of age 1 pollock (or pollock smaller than 20 cm when age data are unavailable) in the annual eastern Bering Sea bottom-trawl survey. Also, bottom-trawl survey estimates of age 1 recruitment, when regressed against age 3 pollock estimates from catch-age models, indicate a linear relationship. This had been used to project age 3 numbers in population forecasts. Our method does not require external regressions since the necessary accounting is done explicitly, within a standard age-structured model. The key advantage in our approach is that the observation and process errors are maintained and their effect can be evaluated.

It appears that the annual bottom trawl survey does not fully cover the distribution of age 1 pollock. This is especially evident for the 1989 year-class that the survey found to be slightly below average, but upon recruitment to the fishery, was a very strong year-class. It appears that a significant amount of this year-class was distributed in the Russian EEZ—beyond the standard survey area—or unavailable to bottom trawl gear (perhaps in mid-water). In 1996, Russian scientists reported the 1995 year-class to be strong, but it appeared to be below average in the U.S. survey. However, in the 1997 EIT survey the 1995 year-class was abundant adjacent to the Russian EEZ.

The coefficient of variation or "CV" (reflecting uncertainty) on the strength of the 1996 year-class is about 25% for Model 1 (down from 39% last year). The 1996 year-class appears to be moderately strong. However, the 95% confidence bounds for the 1996 year-class are only slightly above mean recruitment for all years since 1964 (Fig. 1.43). Adding the effect of the surface currents on recruitment success appears to be a plausible mechanism but it does not reduce the degree of uncertainty in the magnitude of the 1996 year-class. This is due to the fact that we now have 7 direct observations of this year class from survey data: the EIT survey conducted in 1997, 1999, and 2000 and the bottom trawl surveys in 1997, 1998, 1999, and 2000 (though 2- and 3-year olds are less available to bottom-trawl survey gear).

1.7. Projections and harvest alternatives

1.7.1. Amendment 56 Reference Points

Amendment 56 to the BSAI Groundfish Fishery Management Plan (FMP) defines "overfishing level" (OFL), the fishing mortality rate used to set OFL (F_{OFL}), the maximum permissible ABC, and the fishing mortality rate used to set the maximum permissible ABC. The fishing mortality rate used to set ABC (F_{ABC}) may be less than this maximum permissible level, but not greater. Estimates of reference points related to maximum sustainable yield (MSY) are currently available. However, the extent of their reliability is questionable. We therefore present both reference points for pollock in the BSAI to retain the option for classification in either Tier 1 or Tier 3 of Amendment 56. These Tiers require reference point estimates for biomass level determinations. For our analyses, we selected the following values from Model 1 results computed based on recruitment from post-1976 spawning events:

$B_{100\%}$ = **6,525** t female spawning biomass[2]

$B_{40\%}$ = **2,610** t female spawning biomass

$B_{35\%}$ = **2,300** t female spawning biomass

B_{msy} = **2,143** t female spawning biomass

1.7.2. Specification of OFL and Maximum Permissible ABC

For Model 1, the year 2000 spawning biomass is estimated to be 3,186 thousand tons (at the time of spawning, assuming the stock is fished at F_{msy}). This is well above the B_{msy} value of 2,143. Under Amendment 56, Tier 1a, the harmonic mean value is considered a risk-averse policy provided reliable estimates of F_{msy} and its pdf are available. The harmonic mean value for F_{msy} computations is somewhat different from the procedure outlined in Tier 1 of Amendment 56. Here the harmonic mean is computed from the estimated pdf for the year 2002 yield under F_{msy} rather than first finding the harmonic mean of F_{msy} and applying its value to the maximum likelihood estimate for the year 2002 stock size. The method we use results in somewhat lower ABC values since uncertainty in both the F_{msy} value and future stock size are both considered.

Corresponding values under Tier 3 are 2,964 thousand tons for year 2001 spawning values (under $F_{40\%}$ policy). This is well above the $B_{40\%}$ value of 2,610. The OFL's and maximum permissible ABC values by both methods are thus:

	OFL	Max ABC
Tier 1a	**3,531 thousand t**	**2,108 thousand t**
Tier 3a	**2,833 thousand t**	**2,269 thousand t**

1.7.3. ABC Recommendation

Currently, the biomass of eastern Bering Sea pollock appears to be quite high and decreasing. The total begin-year age-3+ biomass in 2002 is projected to be about 9.8 million t. The estimated female spawning biomass projected to the time of spawning in the year 2002 is about **2,964** thousand tons, well above of the

[2] Note that another theoretical "unfished spawning biomass level" (based on stock-recruitment relationship $\tilde{B}_0$) is somewhat lower (5,861 t).

$B_{40\%}$ level of **2,610** thousand tons and well above the $B_{35\%}$ and the value estimated for B_{msy} (**2,300** and **2,143** respectively; Fig. 1.44).

For the year 2002, maximum permissible ABC alternatives based on the $F_{40\%}$ and harmonic-mean F_{msy} are 2,269 and 2,108 thousand tons, respectively for the reference model (F_{msy} harvests based on the harmonic mean value) as shown in Table 1.13 for Model 1. However, subsequent recruitment has been below average (though is highly uncertain). Hence, short-term projections (shown below) predict that the spawning stock is likely to drop below the $B_{40\%}$ and B_{msy} levels. While we feel there is nothing intrinsically wrong with having the population drop below it's optimal level (since under perfect management, it is expected to be below the target exactly half of the time), choosing a harvest level that reduces this likelihood might 1) provide stability to the fishery; 2) provide added conservation given the current Steller sea lion population declines; and 3) provide added conservation due to unknown stock removals in Russian waters. We therefore consider it prudent to recommend a harvest level lower than the maximum permissible values. As an example, under constant catch scenarios of 1.4 and 1.3 million tons, the stock is expected to remain well above the $B_{40\%}$ level (Fig. 1.45).

1.7.4. Standard Harvest Scenarios and Projection Methodology

This year, a standard set of projections is required for each stock managed under Tiers 1, 2, or 3, of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2001 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2001 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2001. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2002, are as follow (A "*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2002 recommended in the assessment to the *max* F_{ABC} for 2002. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 1997-2001 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above one-half of its MSY level in 2004 and above its MSY level in 2014 under this scenario, then the stock is not overfished.)

Scenario 7: In 2002 and 2003, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2014 under this scenario, then the stock is not approaching an overfished condition.)

1.7.5. Projections and status determination

For the purposes of these projections, we present results based on selecting the $F_{40\%}$ harvest rate as the max F_{ABC} value and use $F_{35\%}$ as a proxy for F_{msy}. Scenarios 1 through 7 were projected 14 years from 2001 (Table 1.17). Under Scenario 1, the expected spawning biomass will decrease to slightly below $B_{35\%}$ then increase to above $B_{40\%}$ by the year 2007 (Fig. 1.44). Under this scenario, the yields are expected to vary between 1.0 – 1.8 million tons. If the highly conservative catch levels (estimated from the last 5 years) are to continue, then the stock is not projected to drop below $B_{40\%}$ at any time in the future (Fig. 1.46).

Any stock that is below its MSST is defined to be overfished. Any stock that is expected to fall below its MSST in the next two years is defined to be approaching an overfished condition. Harvest scenarios 6 and 7 are used in these determinations as follows:

Is the stock overfished? This depends on the stock's estimated spawning biomass in 2002:

a) If spawning biomass for 2002 is estimated to be below ½ $B_{35\%}$ the stock is below its MSST.

b) If spawning biomass for 2002 is estimated to be above $B_{35\%}$, the stock is above its MSST.

c) If spawning biomass for 2002 is estimated to be above ½ $B_{35\%}$ but below $B_{35\%}$, the stock's status relative to MSST is determined by referring to harvest scenario 6 (Table 1.17). If the mean spawning biomass for 2012 is below $B_{35\%}$, the stock is below its MSST. Otherwise, the stock is above its MSST.

Is the stock approaching an overfished condition? This is determined by referring to harvest Scenario 7:

a) If the mean spawning biomass for 2004 is below ½ $B_{35\%}$, the stock is approaching an overfished condition.

b) If the mean spawning biomass for 2004 is above $B_{35\%}$, the stock is not approaching an overfished condition.

c) If the mean spawning biomass for 2004 is above ½ $B_{35\%}$ but below $B_{35\%}$, the determination depends on the mean spawning biomass for 2014. If the mean spawning biomass for 2014 is below $B_{35\%}$, the stock is approaching an overfished condition. Otherwise, the stock is not approaching an overfished condition.

For scenarios 6 and 7, we conclude that pollock is not below MSST for the year 2002, nor is it expected to be approaching an overfished condition based on Scenario 7.

1.8. Other considerations

1.8.1. Ecosystem concerns

In general, a number of key issues for ecosystem conservation and management can be highlighted. These include:

- Preventing overfishing;
- Avoiding habitat degradation;
- Minimizing incidental bycatch (via multi-species analyses of technical interactions);
- Controlling the level of discards; and
- Considering multi-species trophic interactions relative to harvest policies.

For the case of pollock in the EBS, the NPFMC and NMFS continue to manage the fishery on the basis of these issues in addition to the single-species harvest approach. The prevention of overfishing is clearly set out as a main guideline for management. Habitat degradation has been minimized in the pollock fishery by converting the industry to pelagic-gear only. Bycatch in the pollock fleet is closely monitored by the NMFS observer program and managed on that basis. Discarding rates have been greatly reduced in this fishery and multi-species interactions is an ongoing research project within NMFS with extensive food-habit studies and simulation analyses to evaluate a number “what if” scenarios with multi-species interactions.

A large body of research on changes in the physical environment is ongoing at the Alaska Fisheries Science Center in collaboration with oceanographers at a number of institutions. Within the Center, we pursued application of the OSCURS model (Ingraham and Miyahara 1988) to describe changes in the Bering Sea that may have affected early-life conditions of pollock. The OSCURS model represents a drift-simulator that uses sea-level pressure data to predict surface current movements. The observed pressure data are used to derive winds and obtain measures of drift from arbitrary locations in the ocean. Arsenev (1967) presented drift patterns for the Bering Sea based on limited drift observations from Soviet research vessels during the 1960s. Direct observation of drift has been shown to be consistent with the magnitude and type of pattern expected based on simulations from the OSCURS model (e.g., Ingraham and Miyahara 1988). To enhance the description of Arsenev, we conducted OSCURS model runs from each month over a grid of points throughout the Eastern Bering sea from 1960-2000. Computing the monthly average over these years a “climatology” of surface currents indicates strong seasonal shifts (Fig. 1.47). The degree to which these seasonal patterns affect pollock abundance distribution and survival is an ongoing research project at the AFSC in collaboration with other climate and oceanographic research groups (e.g., the South East Bering Sea Carrying Capacity work). In addition to describing the general patterns of surface currents within the Bering Sea, these analyses provide the ability to scrutinize the degree of inter-annual variability in surface advection patterns. For example, examining the current patterns for April in different years gives some indication of the kind of inter-annual variability in current patterns (Fig. 1.48). Given alternative hypotheses on the importance of different spawning distributions (e.g., Hinckley 1987) these patterns provide insight on factors that may lead to high survival levels for eggs and larvae. For example, advection in the months subsequent to peak spawning (e.g., April) may provide a good indication of movement of eggs and larvae into prime nursery areas. To date, implementation of an advection model within the stock assessment model has had relative little impact on values critical for harvest management regulations.

1.8.2. Fishing fleet dynamics

It has become common knowledge that several (most) vessels fishing for pollock have made gear modifications designed to reduce the take of under-sized fish. This may change the effective selectivity of the gear in a predictable way. While our approach allows for changes in selectivity, further analyses on this effect may be warranted. Other substantial changes are occurring with the implementation of the RPA's and the American Fisheries Act (AFA). These have reduced the "race for fish" that was common in years before 1999. The impact of the AFA reduces bycatch and improves recovery percentages. In addition, the ability to avoid small fish will be enhanced since the fishery occurs over longer periods with lower daily harvest rates.

1.9. Summary

Summary results are given in Table 1.18.

1.10. Acknowledgements

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1.12. Tables

Table 1.1 Catch from the eastern Bering Sea by area, the Aleutian Islands, the Donut Hole, and the Bogoslof Island area, 1979-2001. (2001 values set equal to TAC). The southeast area refers to the EBS region east of 170W; the Northwest is west of 170W.

	Eastern Bering Sea			Aleutians	Donut Hole	Bogoslof I.
Year	**Southeast**	**Northwest**	**Total**			
1979	368,848	566,866	935,714	9,504		
1980	437,253	521,027	958,280	58,156		
1981	714,584	258,918	973,502	55,516		
1982	713,912	242,052	955,964	57,978		
1983	687,504	293,946	981,450	59,026		
1984	442,733	649,322	1,092,055	81,834	181,200	
1985	604,465	535,211	1,139,676	58,730	363,400	
1986	594,997	546,996	1,141,993	46,641	1,039,800	
1987	529,461	329,955	859,416	28,720	1,326,300	377,436
1988	931,812	296,909	1,228,721	30,000	1,395,900	87,813
1989	904,201	325,399	1,229,600	15,531	1,447,600	36,073
1990	640,511	814,682	1,455,193	79,025	917,400	151,672
1991	712,206	505,095	1,217,301	78,649	293,400	264,760
1992	663,457	500,983	1,164,440	48,745	10,000	160
1993	1,095,314	231,287	1,326,601	57,132	1,957	886
1994	1,183,360	180,098	1,363,458	58,637	NA	566
1995	1,170,828	91,939	1,262,766	64,429	trace	264
1996	1,086,840	105,938	1,192,778	29,062	trace	387
1997	820,050	304,543	1,124,593	25,940	trace	168
1998	965,766	135,399	1,101,165	23,822	trace	136
1999	814,622	177,378	988,674	965	trace	29
2000	839,175	293,532	1,132,707	1,244	NA	28
2001	NA	NA	1,400,000	800	NA	29

1979-1989 data are from Pacfin.
1990-1999 data are from NMFS Alaska Regional Office, includes discards.
2001 catch assuming full EBS TAC will be taken.

Table 1.2. Estimated retained, discarded, and percent discarded of total catch in the Aleutians, Northwest and Southeastern Bering Sea, 1990-2000. Source: NMFS Blend database.

Area	**Year**	**Catch Retained**	**Discard**	**Total**	**Discard Percentage**
Southeast (51)		582,660	57,851	640,511	
Northwest (52)		764,369	50,313	814,682	
Aleutians		69,682	9,343	79,025	
Total	**1990**	1,416,711	117,507	1,534,218	7.7%
Southeast (51)		614,889	97,317	712,206	
Northwest (52)		458,610	46,485	505,095	
Aleutians		73,608	5,041	78,649	
Bogoslof		245,467	19,293	264,760	
Total	**1991**	1,318,966	163,095	1,482,061	11.0%
Southeast (51)		600,861	62,596	663,457	
Northwest (52)		445,811	55,172	500,983	
Aleutians		45,246	3,498	48,745	
Total	**1992**	1,091,919	121,266	1,213,185	10.0%
Southeast (51)		1,011,020	84,294	1,095,314	
Northwest (52)		205,495	25,792	231,287	
Aleutians		55,399	1,733	57,132	
Total	**1993**	1,271,914	111819	1,383,732	8.1%
Southeast (51)		1,091,547	91,813	1,183,360	
Northwest (52)		164,020	16,078	180,098	
Aleutians		57,325	1,311	58,637	
Total	**1994**	1,312,892	109,202	1,422,094	7.7%
Southeast (51)		1,083,381	87,447	1,183,360	
Northwest (52)		82,226	9,713	91,939	
Aleutians		63,047	1,382	64,429	
Total	**1995**	1,228,654	98,542	1,339,728	7.4%
Southeast (51)		1,015,473	71,367	1,086,840	
Northwest (52)		101,100	4,838	105,938	
Aleutians		28,067	994	29,062	
Total	**1996**	1,145,133	77,206	1,222,339	6.3%
Southeast (51)		749,007	71,043	820,050	
Northwest (52)		281,986	22,557	304,543	
Aleutians		25,323	617	25,940	
Total	**1997**	1,056,316	94,217	1,150,533	8.2%
Southeast (51)		950,631	15,135	965,767	
Northwest (52)		133,818	1,581	135,399	
Aleutians		23,657	164	23,822	
Total	**1998**	1,108,106	16,881	1,124,987	1.5%
Southeast (51)		756,047	27,100	783,148	
Northwest (52)		204,785	1,912	206,697	
Aleutians		529	480	1,010	
Total	**1999**	961,362	29,492	990,855	3.0%
Southeast (51)		819,497	19,677	839,175	
Northwest (52)		291,590	1,941	293,532	
Aleutians		455	790	1,244	
Total	**2000**	1,111,543	22,408	1,133,951	2.0%

Table 1.3. Eastern Bering Sea walleye pollock catch by age in numbers (millions), 1979-2000.

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14+	Total
1979	101.4	543.2	720.0	420.2	392.6	215.5	56.3	25.7	35.9	27.5	17.6	7.9	3.0	0.5	2,567.3
1980	9.8	462.4	823.3	443.5	252.2	211.0	83.7	37.6	21.8	23.9	25.5	15.9	7.7	2.5	2,420.7
1981	0.6	72.2	1012.9	638.0	227.0	102.9	51.7	29.6	16.1	9.4	7.5	4.6	1.5	0.6	2,174.6
1982	4.8	25.3	161.4	1172.4	422.4	103.7	36.0	36.0	21.5	9.1	5.4	3.2	1.9	0.7	2,003.7
1983	5.1	118.6	157.8	313.0	817.0	218.3	41.4	24.7	19.8	11.1	7.6	4.9	3.5	1.7	1,744.5
1984	2.1	45.8	88.6	430.8	491.9	654.3	133.9	35.6	25.1	15.7	7.1	2.5	2.9	1.7	1,938.0
1985	2.7	55.3	382.2	122.1	366.7	322.3	444.3	112.8	36.7	25.9	24.9	10.7	9.4	4.0	1,919.9
1986	3.1	86.0	92.3	748.5	214.1	378.1	221.9	214.2	59.7	15.2	3.3	2.6	0.3	1.2	2,040.4
1987	0.0	19.9	112.2	78.0	415.8	139.6	123.2	91.2	248.6	54.4	38.9	21.6	29.1	6.1	1,378.5
1988	0.0	10.7	455.2	422.8	252.8	545.9	225.4	105.2	39.3	97.1	18.3	10.2	3.8	5.5	2,192.2
1989	0.0	4.8	55.3	149.5	452.6	167.3	574.1	96.6	104.1	32.5	129.5	10.9	4.0	2.6	1,783.8
1990	1.3	33.2	57.3	220.7	201.8	480.3	129.9	370.4	66.1	102.5	9.1	60.4	8.5	4.7	1,746.2
1991	1.0	60.9	40.7	85.4	141.5	156.9	396.4	51.6	217.1	22.1	114.7	15.2	74.4	60.9	1,438.8
1992	0.0	79.0	721.7	143.5	98.1	125.0	145.4	276.8	109.3	165.4	59.4	50.2	14.2	91.0	2,079.0
1993	0.1	9.2	275.0	1144.5	103.0	64.3	62.2	53.5	84.9	21.8	34.5	12.6	13.1	26.5	1,905.2
1994	0.3	31.5	59.8	383.4	1109.5	180.5	54.9	21.0	13.5	20.1	9.1	10.7	7.6	15.7	1,917.5
1995	0.0	0.3	75.3	146.6	398.4	764.7	131.8	34.9	10.9	6.0	15.3	4.4	7.1	11.3	1,606.9
1996	0.0	9.5	19.7	43.8	144.9	350.7	486.3	190.4	32.9	14.8	8.9	8.8	4.1	11.3	1,326.1
1997	0.1	65.4	33.2	107.1	470.6	290.8	255.9	198.9	62.9	14.2	6.5	5.1	3.1	14.8	1,528.8
1998	0.0	36.3	86.7	72.3	160.8	704.0	203.6	128.6	107.6	29.1	5.7	6.3	3.0	7.4	1,551.5
1999	0.1	7.5	296.5	219.5	105.0	154.8	475.9	131.4	57.3	33.1	3.9	2.1	0.4	2.5	1,490.0
2000	0.0	15.7	82.1	427.2	345.8	106.2	168.5	353.3	86.8	29.1	22.8	5.7	1.5	1.5	1,646.3

Table 1.4. Numbers of fishery samples used for lengths (measured) and age determinations (aged) by sex and strata, 1991-2000, of pollock as sampled by the NMFS observer program.

	Strata	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Measured males	Aleutians	34,023	33,585	33,052	28,465	21,993	12,336	10,477	6,906	75	70
	Northwest	126,023	110,487	38,524	28,169	17,909	22,290	58,307	32,185	16,629	43,897
	SE A Season	198,835	150,554	122,436	138,338	127,876	148,706	123,385	134,743	35,702	62,300
	SE B Season	102,225	134,371	143,420	153,336	175,524	193,832	114,826	205,309	38,208	62,855
Total		461,106	428,997	337,432	348,308	343,302	377,164	306,995	351,326	92,613	169,122
Measured females	Aleutians	14,620	19,079	21,055	16,125	16,475	8,792	9,056	5,368	60	114
	Northwest	124,934	114,778	39,985	28,185	19,282	22,144	51,358	39,576	19,019	42,162
	SE A Season	184,351	142,016	112,602	146,918	124,000	140,868	102,530	108,645	31,791	55,800
	SE B Season	90,056	136,626	135,661	146,540	150,632	149,583	105,999	174,729	35,019	40,233
Total		413,961	412,499	309,303	337,768	310,389	321,387	268,943	295,104	85,889	138,309
Aged males	Aleutians	22	110	81	157	73	86	15	142	0	0
	Northwest	320	179	147	132	123	0	326	216	312	269
	SE A Season	373	454	451	200	297	470	431	588	533	660
	SE B Season	248	317	475	571	415	442	284	307	728	833
Total		963	1,060	1,154	1,060	908	998	1,056	1,098	1,573	1,762
Aged females	Aleutians	23	121	82	151	105	77	15	166	0	0
	Northwest	340	178	153	142	131	0	326	236	312	313
	SE A Season	385	458	478	201	313	451	434	652	485	616
	SE B Season	233	332	458	574	392	434	312	308	725	574
Total		981	1,089	1,171	1,068	941	962	1,087	1,192	1,522	1,504

Table 1.5. Sampling effort of pollock in the EBS based on the NMFS bottom trawl survey 1982-2001.

Year	Number of Hauls	Lengths	Aged
1982	329	40,001	1,611
1983	354	78,033	1,931
1984	355	40,530	1,806
1985	353	48,642	1,913
1986	354	41,101	1,344
1987	342	40,144	1,607
1988	353	40,408	1,173
1989	353	38,926	1,227
1990	352	34,814	1,257
1991	351	43,406	1,083
1992	336	34,024	1,263
1993	355	43,278	1,385
1994	355	38,901	1,141
1995	356	25,673	1,156
1996	355	40,789	1,387
1997	356	35,536	1,193
1998	355	37,673	1,261
1999	353	32,532	1,385
2000	352	41,762	1,545
2001	355	47,335	1,641

Table 1.6. Biomass (age 1+) of eastern Bering Sea walleye pollock as estimated by surveys 1979-2000(millions of tons).

Year	Bottom trawl survey (t)	EIT Survey (t)	EIT Percent age 3+	Total[3] (t)	Near bottom biomass
1979	3.20	7.46	(22%)	10.66	30%
1980	1.00				
1981	2.30				
1982	2.86	4.90	(95%)	7.76	46%
1983	6.24				
1984	4.89				
1985	4.63	4.80	(97%)	9.43	54%
1986	4.90				
1987	5.11				
1988	7.11	4.68	(97%)	11.79	63%
1989	5.93				
1990	7.13				
1991	5.11	1.45	N/A	6.56	79%
1992	4.37				
1993	5.52				
1994	4.98	2.89	(85%)	7.87	64%
1995	5.41				
1996	3.20	2.31	(97%)	5.51	60%
1997	3.03	2.59	(70%)	5.62	54%
1998	2.21				
1999	3.57	3.29[4]	(95%)	6.86	52%
2000	5.14	3.05		8.19	63%
2001	4.14				

[3] Although the two survey estimates are added in this table, the stock assessment model treats them as separate, independent indices (survey "*q*'s" are estimated).

[4] This figure excludes the zone near the "horseshoe" area of the EBS (southeast) not usually surveyed, the value including this area was 3.35 million tons.

Table 1.7. Distribution of pollock between areas from summer echo integration-trawl surveys on the Bering Sea shelf, 1994-2000. Data are estimated pollock biomass from 14 m below the surface down to 3 m off bottom. Error bounds only quantify acoustic sampling variability.

	Dates	Area $(nmi)^2$	SCA	Biomass (million mt) (percent) E170-SCA	W170	Total Biomass (million mt)	95% Confidence Bounds
1994	Jul 9-Aug 19	78,251	0.312	0.399	2.18	2.89	NA
			(11%)	(14%)	(75%)		
1996	Jul 20-Aug 30	93,810	0.215	0.269	1.83	2.31	2.15-2.48
			(9%)	(12%)	(79%)		
1997	Jul 17-Sept 4	102,770	0.246	0.527	1.82	2.59	2.42-2.76
			(10%)	(20%)	(70%)		
1999	Jun 7-Aug 5*	103,670	0.299	0.579	2.41	3.29	2.95-3.62
			(9%)	(18%)	(73%)		
2000	Jun 7- Aug 2*	106,140	0.393	0.498	2.16	3.05	2.88-3.22
			(13%)	(16%)	(71%)		

* Note four weeks earlier than previous years' surveys

SCA = Sea lion Conservation Area
E170 - SCA = East of 170 W minus SCA
W170 = West of 170 W

Table 1.8. Number of hauls and sample sizes for EBS pollock collected by the EIT surveys.

Year	Stratum	No. Hauls	No. lengths	No. otoliths collected	No. aged
1979	**Total**	25	7,722	NA	2,610
1982	**Total**	48	8,687	NA	2,741
	Midwater, east of St Paul	13	1,725		783
	Midwater, west of St Paul	31	6,689		1,958
	Bottom	4	273		0
1985	**Total** (Legs1 &2)	73	19,872	NA	2,739
1988	**Total**	25	6,619	1,519	1,471
1991	**Total**	62	16,343	2,065	1,663
1994	**Total**	77	21,506	4,973	1,770
	East of 170 W				612
	West of 170 W				1,158
1996	**Total**	57	16,910	1,950	1,926
	East of 170 W				815
	West of 170 W				1,111
1997	**Total**	86	30,535	3,635	2,285
	East of 170 W				936
	West of 170 W				1,349
1999	**Total**	122	42,364	4,946	2,446
	East of 170 W	45	13,842	1,945	946
	West of 170 W	77	28,522	3,001	1,500
2000	**Total**	128	43,729	3,459	2,253
	East of 170 W	32	7,721	850	850
	West of 170 W	96	36,008	2,609	1,403

Table 1.9. Fishery annual average weights-at-age (kg) as estimated from NMFS observer data. These values are used in the model for computing the predicted fishery catch (in weight) and for computing biomass levels for EBS pollock. NOTE: 2001 weight-at-age is treated as the three-year average of values from 1998-2000.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1964-90	0.007	0.170	0.303	0.447	0.589	0.722	0.840	0.942	1.029	1.102	1.163	1.212	1.253	1.286	1.312
1991	0.007	0.170	0.277	0.471	0.603	0.722	0.837	0.877	0.996	1.109	1.127	1.194	1.207	1.256	1.244
1992	0.007	0.170	0.387	0.454	0.615	0.660	0.745	0.898	0.960	1.151	1.174	1.203	1.132	1.184	1.304
1993	0.007	0.170	0.492	0.611	0.657	0.770	0.934	1.078	1.187	1.238	1.385	1.512	1.632	1.587	1.465
1994	0.007	0.170	0.398	0.628	0.716	0.731	0.709	0.995	1.287	1.228	1.197	1.329	1.308	1.282	1.282
1995	0.007	0.170	0.389	0.505	0.733	0.841	0.854	1.000	1.235	1.314	1.375	1.488	1.402	1.336	1.491
1996	0.007	0.170	0.332	0.448	0.717	0.817	0.964	0.966	1.059	1.142	1.371	1.452	1.487	1.679	1.460
1997	0.007	0.170	0.325	0.468	0.554	0.745	0.890	1.071	1.084	1.236	1.332	1.421	1.570	1.451	1.418
1998	0.007	0.170	0.362	0.574	0.629	0.636	0.778	1.046	1.173	1.242	1.236	1.337	1.443	1.487	1.709
1999	0.007	0.170	0.412	0.492	0.655	0.697	0.750	0.960	1.081	1.347	1.275	1.404	1.500	1.539	1.529
2000	0.007	0.170	0.380	0.501	0.626	0.779	0.773	0.822	1.020	1.046	1.311	1.387	1.504	1.492	1.552
2001	0.007	0.170	0.384	0.522	0.637	0.704	0.767	0.943	1.092	1.212	1.274	1.376	1.482	1.506	1.597

Table 1.10. Pollock sample sizes assumed for the age-composition data likelihoods from the fishery, bottom-trawl survey, and EIT surveys, 1964-2001.

Year	**Fishery**		**Year**	**Fishery**	**BTS**	**EIT**
1964	10		1979	50		25
1965	10		1980	50		
1966	10		1981	50		
1967	10		1982	50	100	48
1968	10		1983	50	100	
1969	10		1984	50	100	
1970	10		1985	50	100	73
1971	10		1986	50	100	
1972	10		1987	50	100	
1973	10		1988	50	100	25
1974	10		1989	50	100	
1975	10		1990	50	100	
1976	10		1991	200	100	62
1977	10		1992	200	100	
1978	50		1993	200	100	
			1994	200	100	77
			1995	200	100	
			1996	200	100	57
			1997	200	100	86
			1998	200	100	
			1999	200	100	122
			2000	200	100	128
			2001		100	

Table 1.11. Results comparing fits Models 1-7. Effective N (sample size) computations are as presented in McAllister and Ianelli (1997). Note: Model 7 total –ln(likelihood) value is not comparable with others (since survey data are disregarded in the model fitting). See text for additional model descriptions.

Fits to data sources	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Total –ln(likelihood)	**-1217.27**	**-1209.07**	**-1230.62**	**-1220.33**	**-1214.45**	**-1216.67**	**-1132.27**
Age Composition data							
Effective N Fishery	200	207	200	199	198	197	201
Effective N Bottom trawl survey	219	202	221	227	227	223	NA
Effective N Hydro acoustic survey	117	116	114	118	117	119	NA
Survey abundance estimates, RMSE*							
Trawl Survey	0.20	0.25	0.19	0.18	0.23	0.22	0.70
EIT survey	0.33	0.32	0.34	0.32	0.34	0.33	0.57
Recruitment Residuals							
Due to Stock	0.24	0.24	0.25	0.24	0.24	0.24	0.24
Residual RMSE	0.39	0.40	0.37	0.40	0.40	0.41	0.39
Total	0.64	0.64	0.62	0.64	0.64	0.65	0.64

*RMSE = $\sqrt{\frac{\sum \ln\left(obs/pred\right)^2}{n}}$

Table 1.12. Results reflecting the stock condition for Models 1-7. Values in parentheses are coefficients of variation (CV's) of values immediately above. See text for model descriptions.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Biomass							
Year 2002 spawning biomass[5]	2,964	3,265	2,894	3,266	3,561	3,921	2,452
Year 2002 spawning biomass[6]	3,186	3,486	3,071	3,541	3,776	4,233	2,612
(CV)	(21%)	(17%)	(22%)	(21%)	(19%)	(19%)	(27%)
2001 spawning biomass	3,790	4,130	3,613	4,229	4,488	5,216	3,033
B_{msy}	2,143	2,306	2,215	2,130	2,395	2,404	2,052
(CV)	(31%)	(31%)	(32%)	(30%)	(30%)	(26%)	(32%)
$B_{40\%}$	2,610	2,745	2,618	2,647	2,829	2,842	2,461
(CV)	(19%)	(19%)	(19%)	(19%)	(18%)	(18%)	(19%)
Percent of B_{msy} spawning biomass	138%	142%	131%	153%	149%	163%	119%
Percent of $B_{40\%}$ spawning biomass	122%	127%	117%	134%	133%	149%	106%
2001 Age 3+ Biomass	11,680	12,695	11,153	12,815	13,501	15,899	9,683
Ratio B_{2001}/B_{2000} (3+ biomass)	93%	94%	95%	98%	96%	97%	93%
Recruitment	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Steepness parameter (h)	0.65	0.64	0.65	0.65	0.64	0.64	0.64
Avg Recruitment (all yrs)	22,629	23,497	22,638	22,963	24,154	27,843	21,844
(CV)	63%	65%	62%	64%	64%	67%	62%
Avg. Recruitment (since 1978)	25,246	26,440	25,219	25,727	27,366	32,287	23,837
(CV since 1978)	67%	68%	65%	68%	67%	68%	67%
1996 year-class	50,253	54,643	44,004	56,736	56,320	71,667	41,179
(CV 1996 year-class)	(21%)	(17%)	(22%)	(20%)	(21%)	(23%)	(24%)
Natural Mortality *(age 3 and older)*	0.300	0.300	0.300	0.300	0.300	0.330	0.300

Table 1.13. Results relating to yield for Models 1-7. See text for model descriptions.

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
2002 Har. Mean F_{msy} yield	2,108	2,297	1,898	2,467	2,352	3,178	1,419
2002 F_{msy} yield	3,531	3,765	3,175	4,090	3,912	5,256	2,735
(CV)	(49%)	(48%)	(49%)	(48%)	(49%)	(48%)	(56%)
Year 2002 $F_{40\%}$ Yield	2,269	2,507	2,117	2,578	2,658	3,620	1,808
Year 2002 $F_{35\%}$ Yield	2,833	3,135	2,621	3,232	3,300	4,502	2,277
MSY (long-term expectation)	1,958	2,027	1,979	1,973	2,087	2,342	1,798
Average F(over ages 1-15)							
F_{msy}	0.67	0.63	0.59	0.73	0.55	0.74	0.74
(CV)	(129%)	(131%)	(126%)	(132%)	(124%)	(135%)	(138%)
$F_{40\%}$	0.377	0.367	0.351	0.392	0.333	0.442	0.429
Full-selection equivalent F's							
F_{msy}	1.234	1.223	0.979	1.355	1.052	1.423	1.343
$F_{40\%}$	0.690	0.717	0.583	0.730	0.639	0.849	0.781
$F_{35\%}$	0.913	0.953	0.760	0.975	0.838	1.136	1.047

[5] At time of spawning, fishing at F_{msy}

[6] At time of spawning, fishing at $F_{40\%}$

Table 1.14 Estimates of numbers at age for the EBS pollock stock under Model 1 (millions).

Year	1	2	3	4	5	6	7	8	9	10+
1964	4,917	3,846	2,194	527	221	346	141	58	32	197
1965	20,392	1,995	2,421	1,534	323	133	213	89	38	153
1966	14,470	8,275	1,257	1,695	945	196	83	136	58	128
1967	27,793	5,871	5,190	864	1,068	599	127	54	90	124
1968	25,684	11,258	3,635	3,369	479	598	349	75	33	132
1969	26,610	10,405	6,976	2,368	1,882	271	351	209	46	102
1970	21,230	10,760	6,384	4,372	1,393	1,113	163	211	125	86
1971	9,855	8,573	6,541	3,843	2,434	780	639	93	120	117
1972	11,324	3,971	5,127	3,668	1,940	1,239	410	334	48	120
1973	27,720	4,564	2,274	2,647	1,717	924	604	203	166	85
1974	21,201	11,142	2,531	1,054	1,080	716	398	264	89	112
1975	17,612	8,499	5,988	1,055	376	395	273	154	104	80
1976	13,304	7,105	4,927	2,676	400	147	162	114	66	80
1977	14,503	5,375	4,199	2,441	1,163	179	68	76	55	70
1978	27,861	5,867	3,227	2,259	1,183	576	91	35	40	66
1979	62,884	11,294	3,568	1,826	1,103	542	268	43	17	51
1980	25,878	25,496	6,889	2,055	916	521	260	130	21	33
1981	29,348	10,499	15,717	4,211	1,130	481	277	139	70	29
1982	15,715	11,919	6,624	10,858	2,530	601	246	144	73	52
1983	52,131	6,385	7,553	4,707	7,100	1,538	356	147	87	76
1984	12,458	21,184	4,052	5,417	3,165	4,511	959	224	93	103
1985	34,188	5,062	13,448	2,915	3,701	2,034	2,771	581	139	119
1986	12,553	13,893	3,214	9,679	1,993	2,381	1,252	1,683	360	156
1987	7,352	5,101	8,821	2,316	6,638	1,289	1,476	766	1,051	318
1988	4,377	2,988	3,243	6,409	1,625	4,514	852	943	491	880
1989	9,159	1,779	1,898	2,337	4,398	1,067	2,843	512	569	833
1990	52,355	3,722	1,129	1,365	1,596	2,864	665	1,684	304	840
1991	24,354	21,279	2,363	806	917	957	1,629	350	913	624
1992	18,296	9,898	13,499	1,677	534	535	526	821	182	796
1993	46,450	7,435	6,272	9,495	1,086	296	276	244	396	479
1994	12,034	18,881	4,729	4,560	6,140	592	134	135	128	489
1995	9,852	4,892	12,016	3,454	3,046	3,598	302	73	76	371
1996	25,453	4,005	3,115	8,804	2,361	1,882	1,996	175	44	283
1997	50,253	10,346	2,547	2,275	6,225	1,589	1,102	1,038	94	187
1998	16,482	20,428	6,581	1,861	1,609	4,192	932	575	559	159
1999	16,233	6,700	12,996	4,812	1,320	1,091	2,499	498	317	404
2000	14,994	6,598	4,261	9,414	3,389	880	688	1,454	280	429
2001	21,180	6,095	4,195	3,077	6,580	2,224	542	386	785	410
Median	19,344	7,270	4,495	2,662	1,602	830	377	206	93	130
Average	22,591	9,037	5,568	3,650	2,255	1,273	708	391	215	257

Table 1.15. Estimated catch-at-age of EBS pollock for Model 1 (millions).

	1	2	3	4	5	6	7	8	9	10+
1964	6	39	107	79	36	51	18	6	3	16
1965	26	20	115	223	51	19	26	9	4	12
1966	20	109	78	220	119	21	8	13	5	11
1967	67	137	557	189	226	111	22	9	13	18
1968	61	256	381	720	99	108	58	12	5	18
1969	95	317	932	423	330	44	58	35	8	20
1970	94	405	1,039	946	296	218	32	43	25	20
1971	58	430	1,382	1,067	664	197	164	24	31	34
1972	66	327	1,355	1,180	606	369	120	96	14	33
1973	209	481	745	1,043	658	339	217	72	58	29
1974	195	1,419	970	481	480	305	166	109	37	45
1975	90	625	2,078	452	155	155	103	57	38	29
1976	54	419	1,424	968	139	48	51	36	20	24
1977	47	254	1,002	737	337	49	18	20	14	17
1978	54	219	662	672	395	187	29	11	13	20
1979	115	395	691	515	349	167	81	13	5	15
1980	36	683	1,046	461	232	128	63	31	5	8
1981	20	89	917	691	278	130	72	35	17	7
1982	6	60	234	1,104	394	104	41	23	12	8
1983	17	25	208	377	877	211	47	19	11	10
1984	4	76	101	365	364	668	151	32	14	17
1985	11	18	331	195	422	299	433	82	20	20
1986	4	47	76	622	219	337	189	230	51	25
1987	1	12	147	106	471	121	177	90	121	36
1988	1	10	76	409	160	587	140	152	77	136
1989	3	6	48	159	461	147	495	87	95	138
1990	11	14	36	110	264	578	167	394	74	188
1991	6	87	86	73	169	215	453	91	246	156
1992	5	49	590	183	117	142	171	250	58	233
1993	8	15	100	1,045	250	100	82	63	91	96
1994	2	29	58	389	1,116	161	32	27	23	78
1995	1	6	114	230	438	786	57	12	11	46
1996	3	8	38	347	188	343	518	42	10	54
1997	6	20	31	89	491	287	284	247	22	35
1998	2	37	74	68	118	711	226	128	122	29
1999	2	14	249	205	114	141	467	104	60	64
2000	2	15	94	460	335	129	145	344	60	75
2001	4	17	108	176	756	377	132	105	192	83

Table 1.16. Estimates of begin-year age 3 and older biomass (thousands of tons) and coefficients of variation (CV) for Model 1 (current assessment) compared to estimates from the 2000-1997 assessments for EBS pollock. NOTE: see Section 1.5.1 for a discussion on the interpretation of age-3+ biomass estimates.

Age 3+ Biomass	Current Assessment	CV	2000 Assessment	CV	1999 Assessment	CV	1998 Assessment	CV	1997 Assessment	CV
1964	1,726	46%	751	35%	917	41%	1,037	30%		
1965	2,196	40%	976	36%	976	32%	1,227	26%		
1966	2,251	41%	1,001	39%	919	31%	1,096	28%		
1967	3,420	33%	1,957	34%	1,858	24%	2,095	22%		
1968	3,876	34%	2,312	36%	2,312	27%	2,510	23%		
1969	5,137	32%	3,379	29%	3,579	22%	3,810	19%		
1970	6,079	30%	3,998	25%	4,479	19%	5,083	15%		
1971	6,580	28%	4,372	21%	5,161	16%	5,813	12%		
1972	6,078	27%	3,984	19%	4,896	15%	5,648	11%		
1973	4,520	32%	2,873	26%	3,357	20%	3,922	14%		
1974	3,193	39%	1,648	41%	1,952	28%	2,342	19%		
1975	3,366	26%	2,536	23%	2,683	18%	3,014	13%		
1976	3,434	22%	2,694	17%	2,748	16%	3,008	13%		
1977	3,444	20%	2,701	13%	2,716	14%	2,894	13%		
1978	3,327	19%	2,608	14%	2,668	15%	2,867	13%	3,244	19%
1979	3,280	19%	2,640	16%	2,720	16%	2,933	15%	3,183	21%
1980	4,322	16%	3,723	15%	3,888	16%	4,294	14%	4,618	19%
1981	8,127	14%	7,834	12%	8,064	13%	8,569	12%	9,190	16%
1982	9,261	13%	9,021	13%	9,229	13%	9,778	12%	10,524	17%
1983	10,298	13%	9,958	12%	10,153	12%	10,705	12%	11,555	16%
1984	10,000	13%	9,518	13%	9,685	12%	10,179	12%	11,028	17%
1985	12,181	11%	11,182	10%	11,370	10%	11,919	11%	12,853	15%
1986	11,381	11%	10,277	10%	10,440	10%	10,913	11%	11,796	16%
1987	11,951	10%	10,636	9%	10,769	9%	11,116	10%	11,952	15%
1988	11,159	10%	9,910	8%	9,991	9%	10,274	10%	11,020	15%
1989	9,394	10%	8,251	9%	8,305	9%	8,546	10%	9,210	16%
1990	7,393	11%	6,473	10%	6,497	10%	6,659	12%	7,240	18%
1991	5,582	12%	4,859	11%	4,842	11%	5,180	13%	5,690	20%
1992	8,898	10%	7,920	9%	7,800	10%	8,294	13%	9,465	21%
1993	11,503	10%	10,233	10%	9,873	10%	10,279	16%	12,086	25%
1994	10,590	11%	9,285	10%	8,622	12%	8,917	18%	10,626	29%
1995	12,617	13%	10,267	12%	8,817	15%	8,680	22%	9,998	32%
1996	10,752	14%	8,556	14%	7,147	17%	6,811	26%	8,142	36%
1997	8,984	16%	7,057	17%	5,710	22%	5,307	31%	6,631	42%
1998	9,335	20%	7,448	22%	5,961	28%	5,133	39%	5,133	39%
1999	12,593	28%	10,772	30%	7,513	36%				
2000	11,680	33%	10,490	34%						
2001	11,145	39%								

Table 1.17 Projections of Model 1 spawning biomass (thousands of tons) for EBS pollock for the 7 scenarios. The values for $B_{100\%}$, $B_{40\%}$, and $B_{35\%}$ are **6,525**; **2,610**; and **2,300** t, respectively.

Sp.Biomass	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2001	3,790	3,790	3,790	3,790	3,790	3,790	3,790
2002	3,186	3,186	3,337	3,345	3,497	3,092	3,186
2003	2,525	2,525	3,031	3,062	3,711	2,285	2,525
2004	2,353	2,353	2,991	3,035	4,118	2,126	2,304
2005	2,461	2,461	3,111	3,159	4,566	2,249	2,304
2006	2,620	2,620	3,288	3,332	4,981	2,397	2,414
2007	2,721	2,721	3,425	3,465	5,302	2,477	2,481
2008	2,751	2,751	3,503	3,542	5,571	2,487	2,488
2009	2,741	2,741	3,533	3,573	5,786	2,465	2,465
2010	2,738	2,738	3,557	3,599	5,970	2,460	2,460
2011	2,753	2,753	3,588	3,632	6,141	2,475	2,475
2012	2,776	2,776	3,620	3,666	6,279	2,497	2,497
2013	2,778	2,778	3,630	3,677	6,376	2,496	2,496
2014	2,760	2,760	3,618	3,667	6,433	2,477	2,477
F	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2001	0.203	0.203	0.203	0.203	0.203	0.203	0.203
2002	0.377	0.377	0.188	0.179	0.000	0.499	0.377
2003	0.361	0.361	0.188	0.179	0.000	0.430	0.361
2004	0.330	0.330	0.188	0.179	0.000	0.396	0.429
2005	0.328	0.328	0.184	0.179	0.000	0.404	0.412
2006	0.331	0.331	0.182	0.179	0.000	0.414	0.416
2007	0.336	0.336	0.182	0.179	0.000	0.422	0.422
2008	0.338	0.338	0.182	0.179	0.000	0.423	0.424
2009	0.339	0.339	0.183	0.179	0.000	0.423	0.423
2010	0.339	0.339	0.183	0.179	0.000	0.423	0.423
2011	0.339	0.339	0.183	0.179	0.000	0.423	0.423
2012	0.340	0.340	0.184	0.179	0.000	0.424	0.424
2013	0.340	0.340	0.184	0.179	0.000	0.424	0.424
2014	0.339	0.339	0.183	0.179	0.000	0.423	0.423
Catch	*Scenario 1*	*Scenario 2*	*Scenario 3*	*Scenario 4*	*Scenario 5*	*Scenario 6*	*Scenario 7*
2001	1,400	1,400	1,400	1,400	1,400	1,400	1,400
2002	2,269	2,269	1,248	1,190	0	2,833	2,269
2003	1,765	1,765	1,206	1,161	0	1,823	1,765
2004	1,376	1,376	1,127	1,095	0	1,407	1,703
2005	1,306	1,306	1,049	1,041	0	1,395	1,482
2006	1,385	1,385	1,063	1,057	0	1,515	1,540
2007	1,488	1,488	1,125	1,112	0	1,624	1,629
2008	1,550	1,550	1,188	1,171	0	1,671	1,671
2009	1,569	1,569	1,225	1,207	0	1,673	1,673
2010	1,568	1,568	1,241	1,222	0	1,663	1,662
2011	1,567	1,567	1,249	1,229	0	1,663	1,663
2012	1,575	1,575	1,256	1,235	0	1,678	1,678
2013	1,580	1,580	1,260	1,240	0	1,679	1,679

Table 1.18. Summary results for Model 1, EBS pollock. Tonnage units are thousands of metric tons.

Age	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
M	0.900	0.450	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300	0.300
Prop.F. Mature	0.000	0.004	0.145	0.321	0.421	0.451	0.474	0.482	0.485	0.500	0.500	0.500	0.500	0.500	0.500
Fish. Selectivity	0.0014	0.0168	0.1487	0.3362	0.6997	1.0692	1.6062	1.8309	1.6238	1.3514	1.2631	1.2631	1.2631	1.2631	1.2631

	Model 1
2002 Spawning biomass	**3,186** t
B_{msy}	**2,143** t
$B_{40\%}$	**2,610** t
$B_{35\%}$	**2,300** t
Yield Considerations	
Year 2002 Harmonic Mean F_{msy} Yield	**2,108** t
Year 2002 Yield F40% (adjusted)	**2,269** t
Full Selection F's	
F_{msy}	**1.234**
$F_{40\%}$	**0.690**
$F_{35\%}$	**0.913**

1.13. Figures

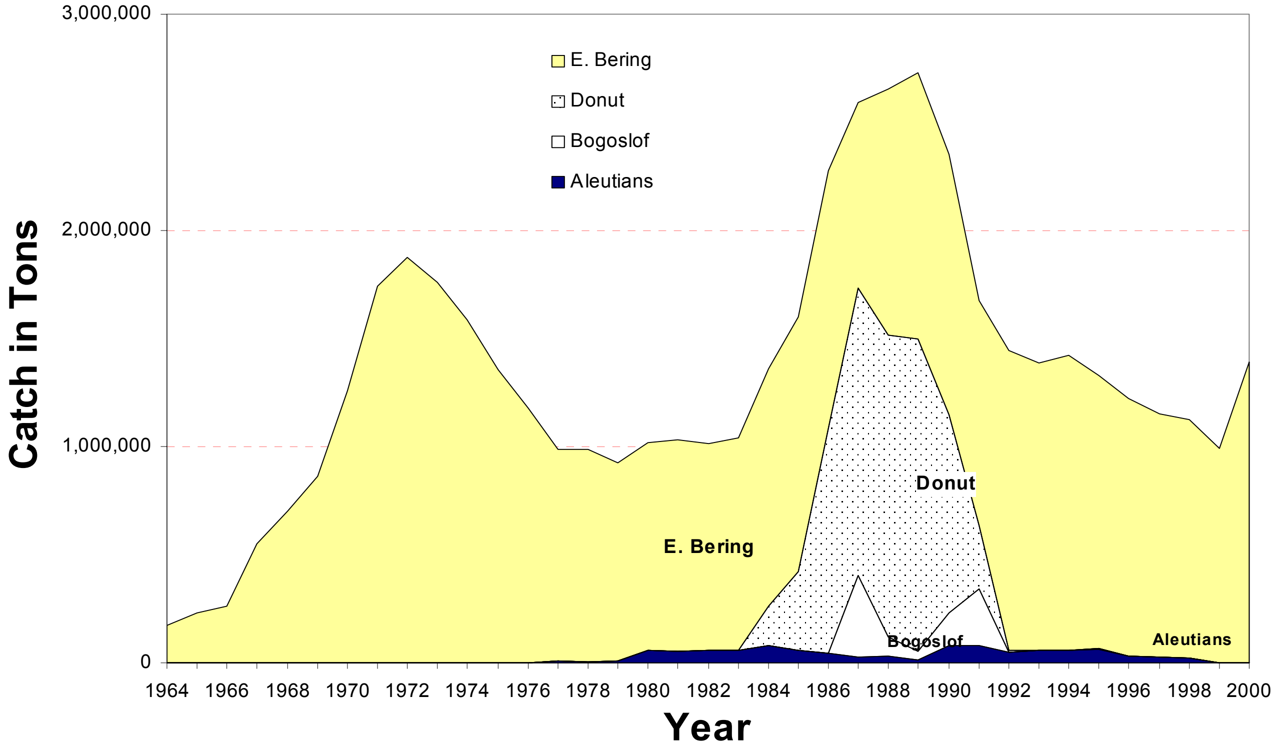


Figure 1.1. Walleye pollock catch in the eastern Bering Sea, Aleutian Islands, Bogoslof Island, and Donut Hole, 1964-2000.

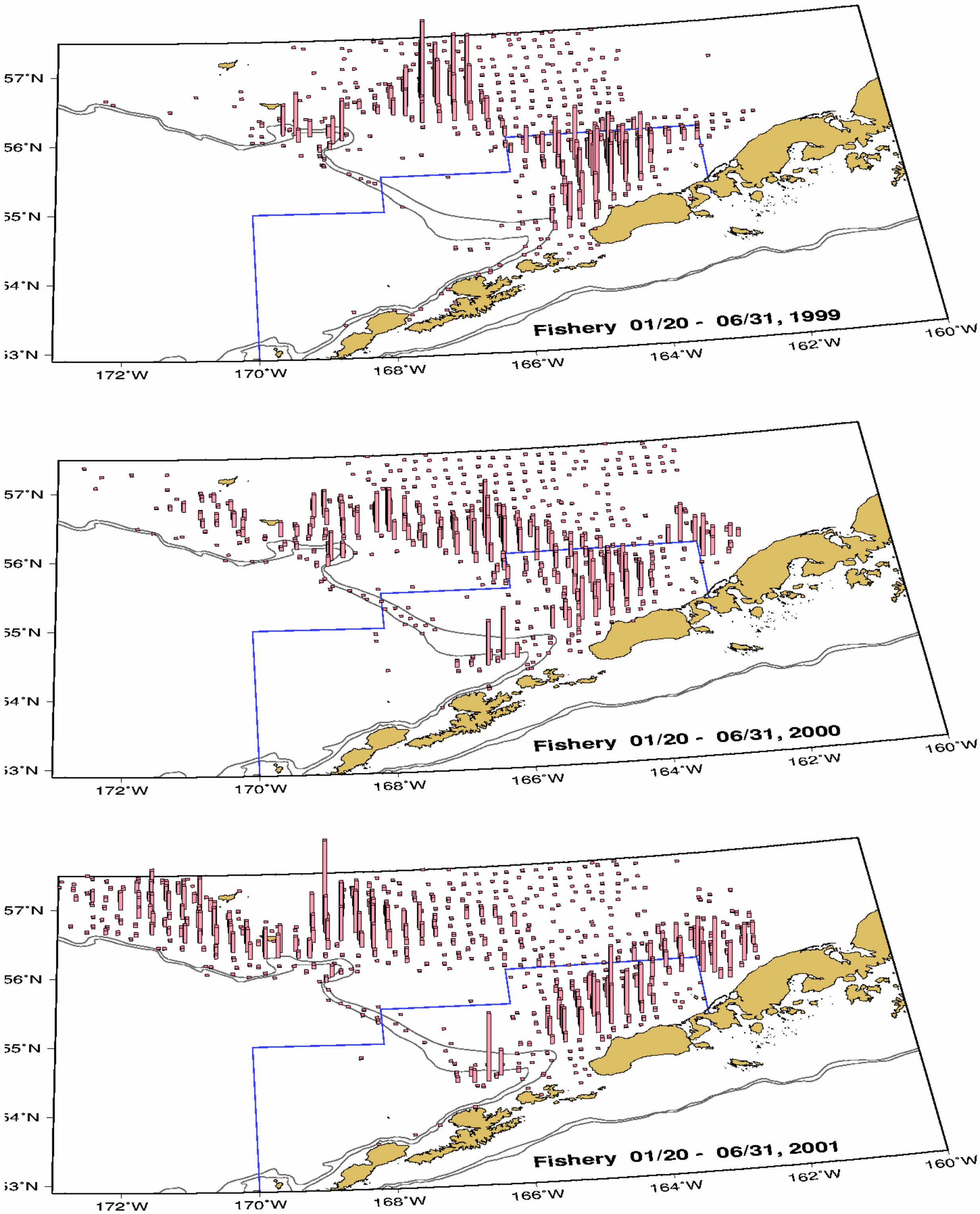


Figure 1.2. Concentrations of the pollock fishery 1999-2001, January - June on the EBS shelf. Line delineates SCA (sea lion conservation area). The column height represents relative removal on the same scale in all years.

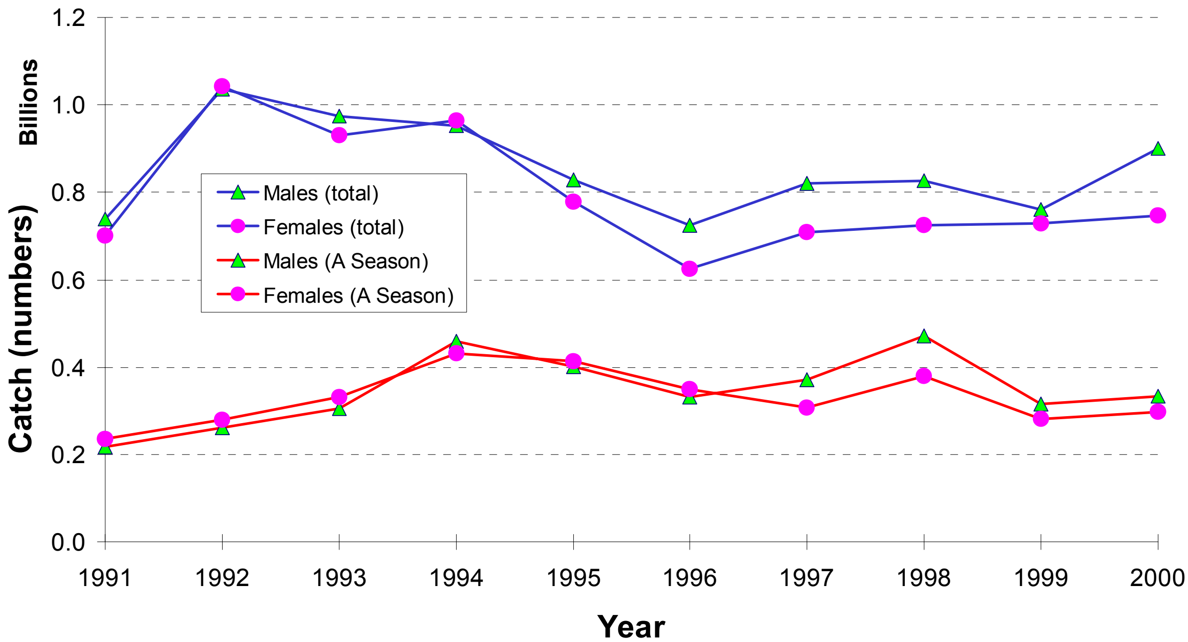


Figure 1.3. Estimate of EBS pollock catch numbers by sex for the “A season” and for the entire fishery, 1991-2000.

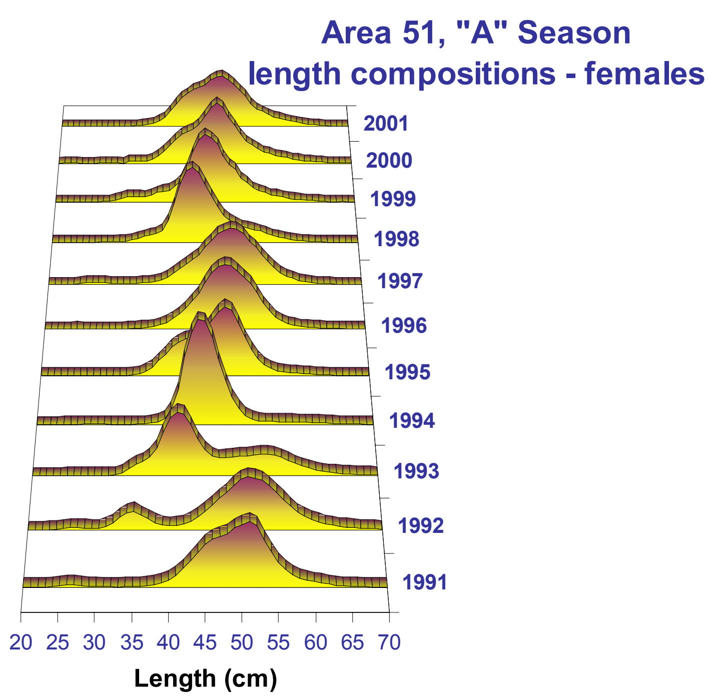


Figure 1.4. Fishery length frequency for the “A season” EBS pollock, 1991-2001. Data for 2001 are preliminary.

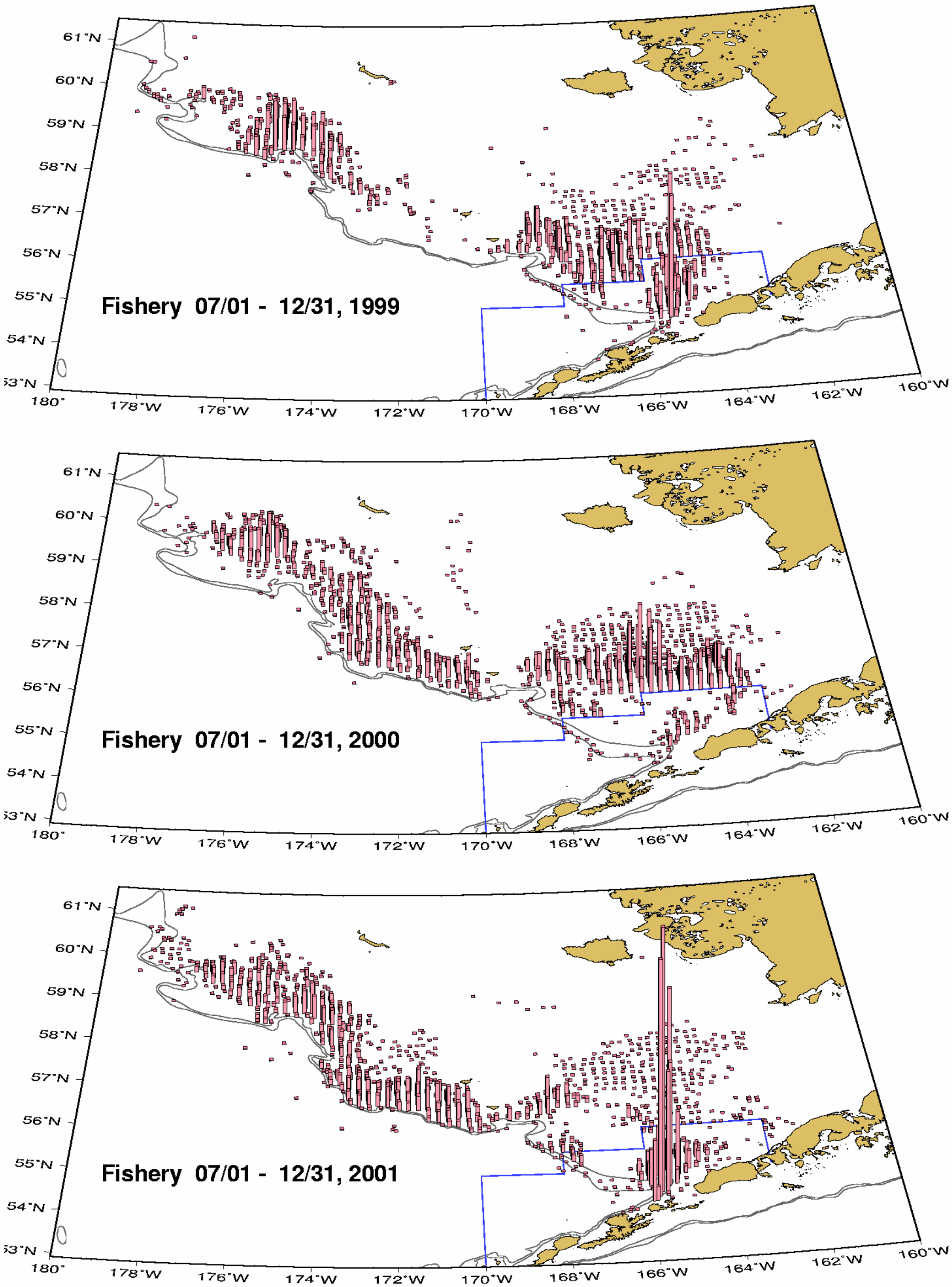


Figure 1.5. Concentrations of the pollock fishery 1999-2001, July – December on the EBS shelf. Line delineates SCA (sea lion conservation area). The density represents relative removal on the same scale over all years.

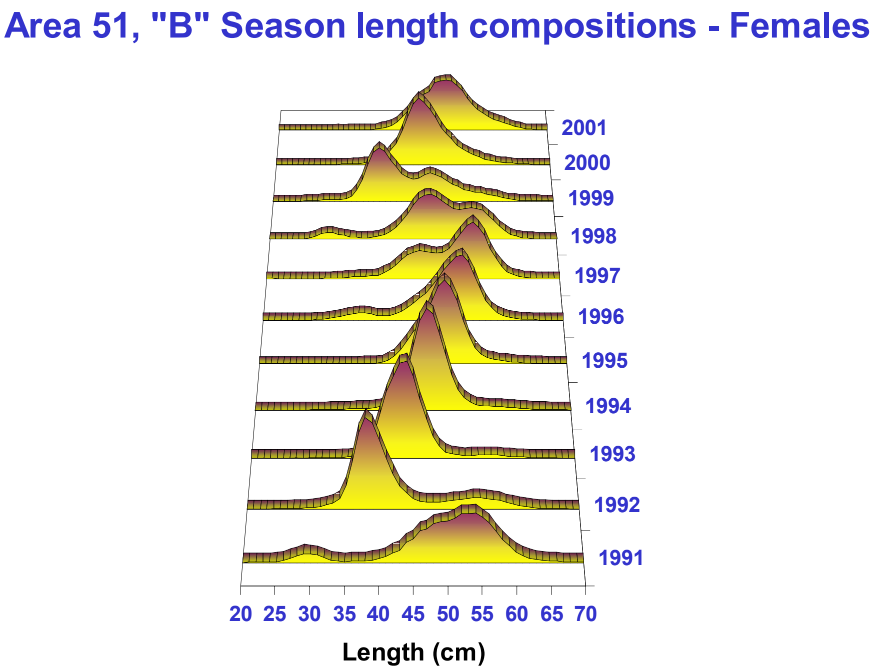


Figure 1.6. Length frequency of EBS pollock observed in period June-December for 1991-2001. Data for 2001 are preliminary.

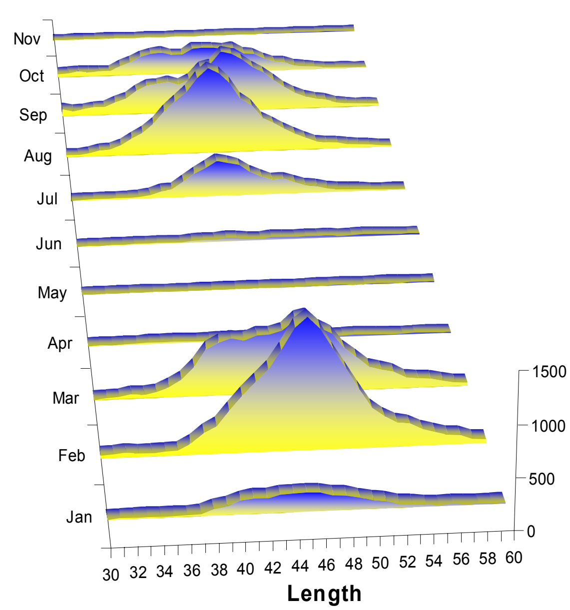


Figure 1.7. Fishery catch-at-length by month approximated by raw observer length-frequency values for the 2000 EBS pollock fishery.

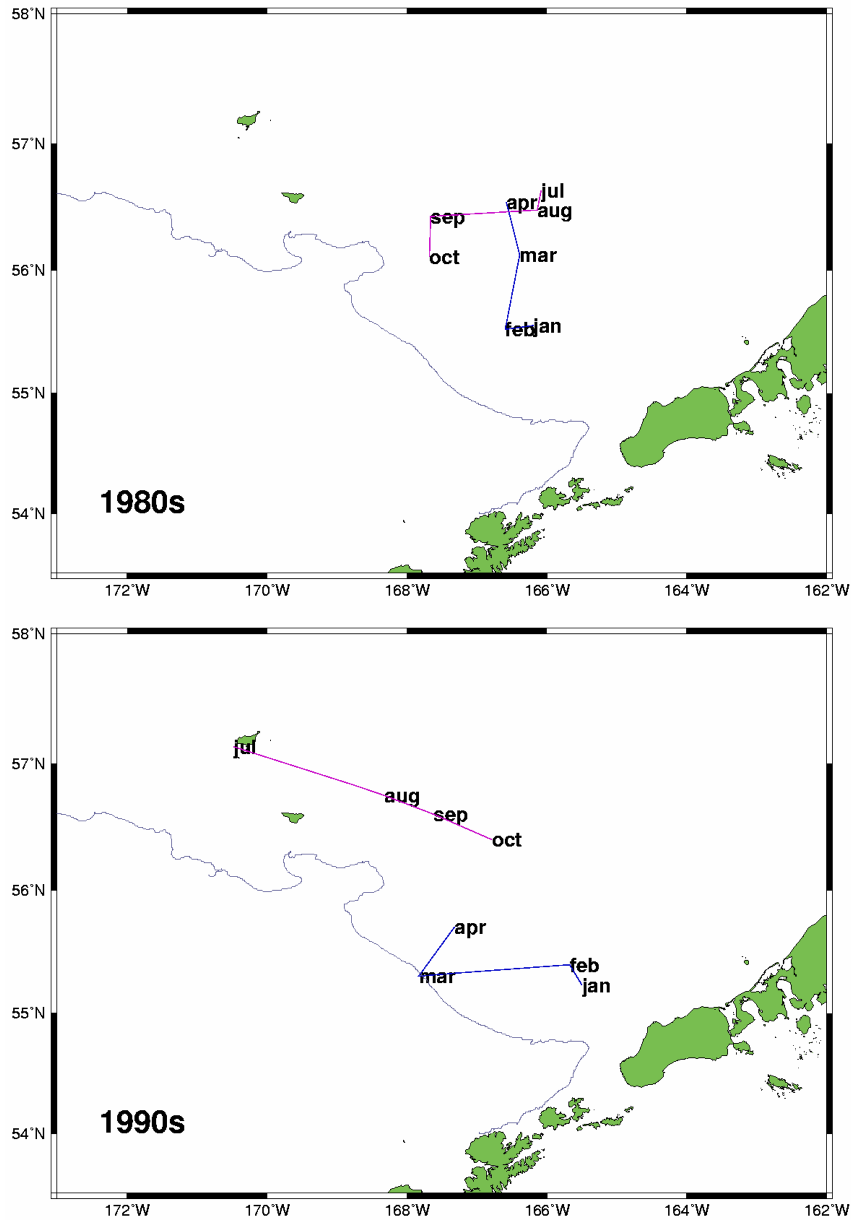


Figure 1.8. Average centers of monthly pollock catch-distribution based on NMFS observer data during the 1980s (top) and the 1990s (bottom).

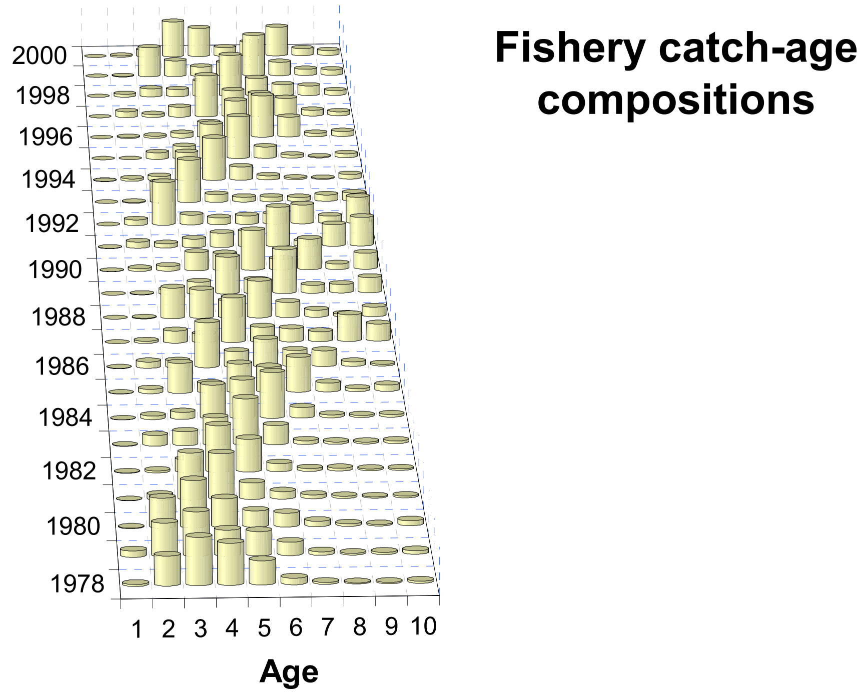


Figure 1.9. EBS walleye pollock fishery catch-at-age data (proportions). Age 10 represents age 10 and older pollock.

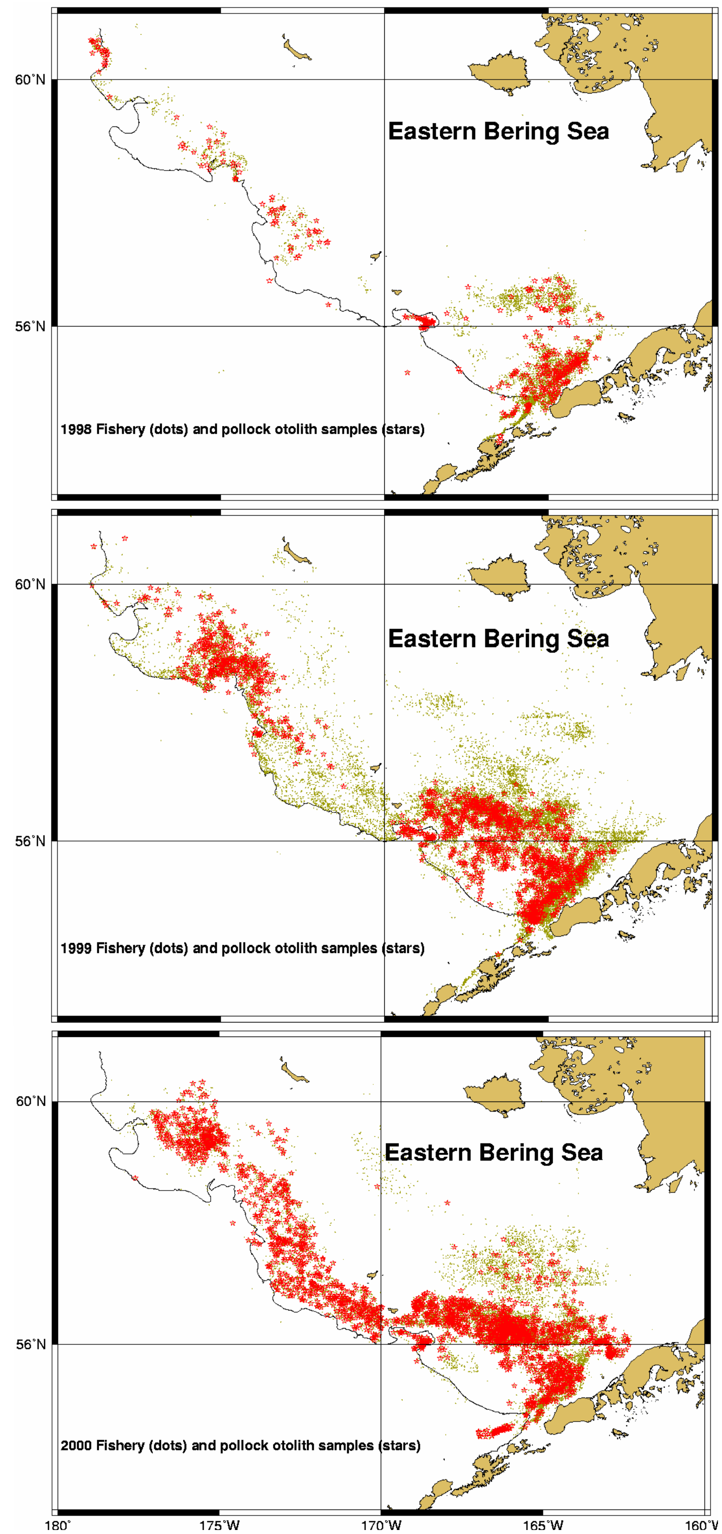


Figure 1.10. EBS pollock fishery sampling locations under the old sampling protocol (1998, top) and under the new protocol (1999, 2000; middle and bottom panels). Points represent haul locations and stars represent hauls were otolith samples were collected.

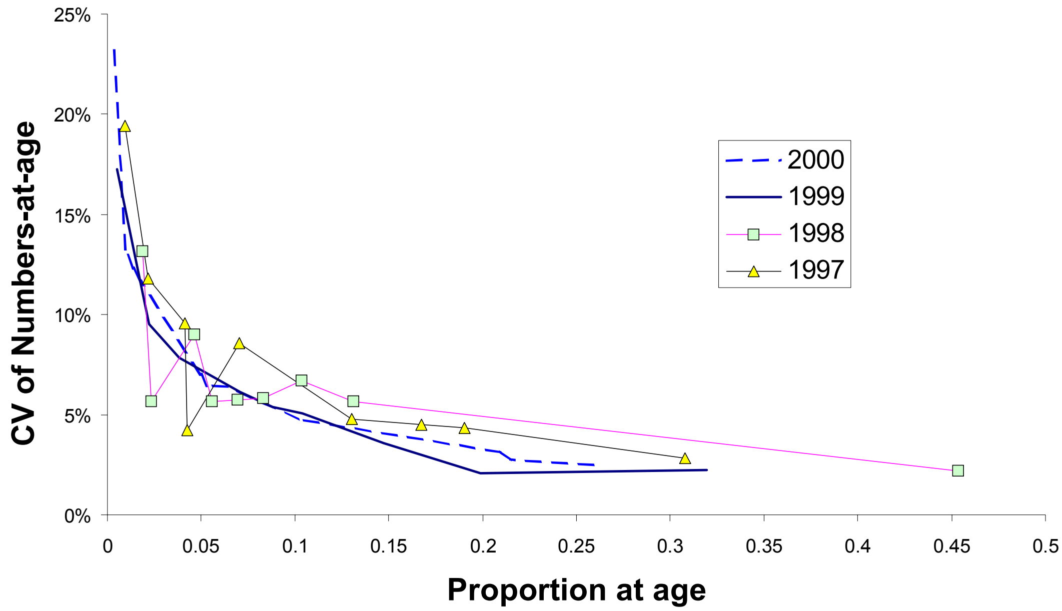


Figure 1.11. Estimated coefficients of variation in catch numbers-at-age from the EBS walleye pollock fishery relative to the proportion of catch numbers-at-age. In 2000 and 1999 the new observer sampling methods are compared with the old sampling protocol of 1997 and 1998.

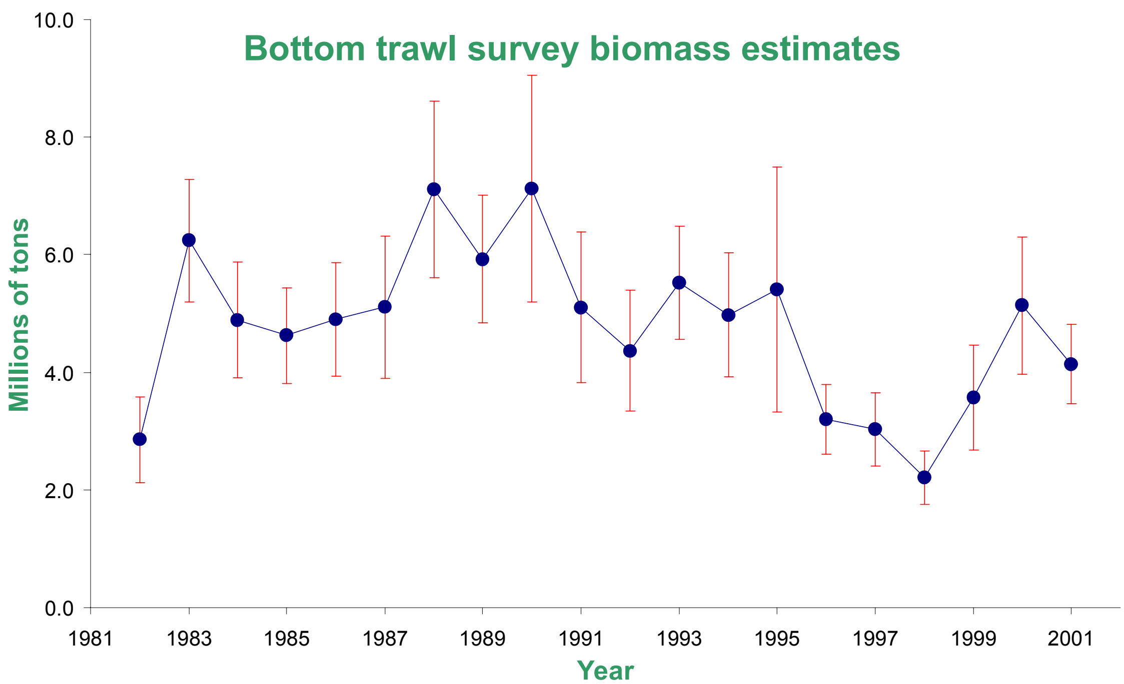
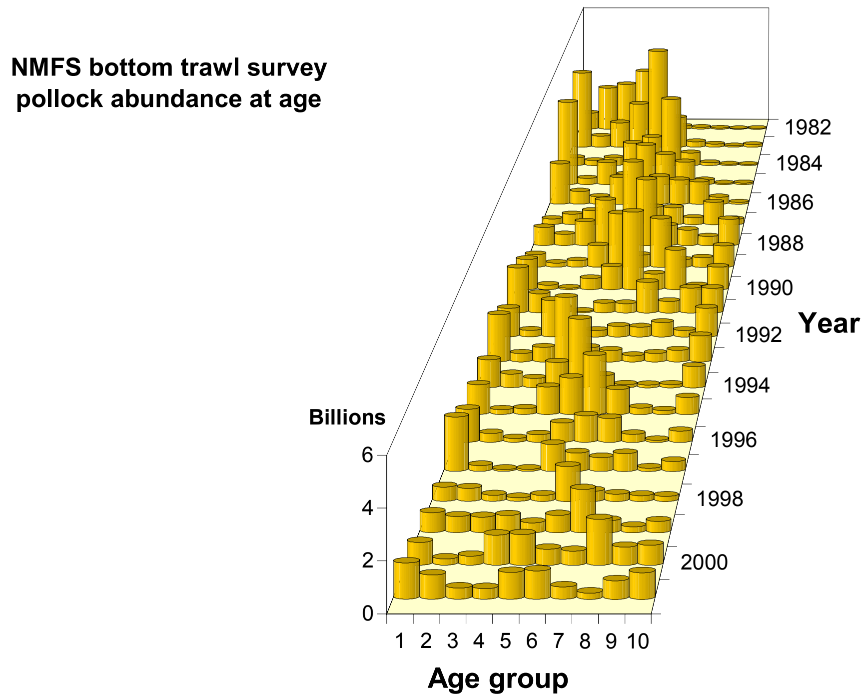


Figure 1.12. Bottom-trawl survey biomass estimates with 95% confidence bounds (based on sampling error) for EBS walleye pollock, 1982-2001.



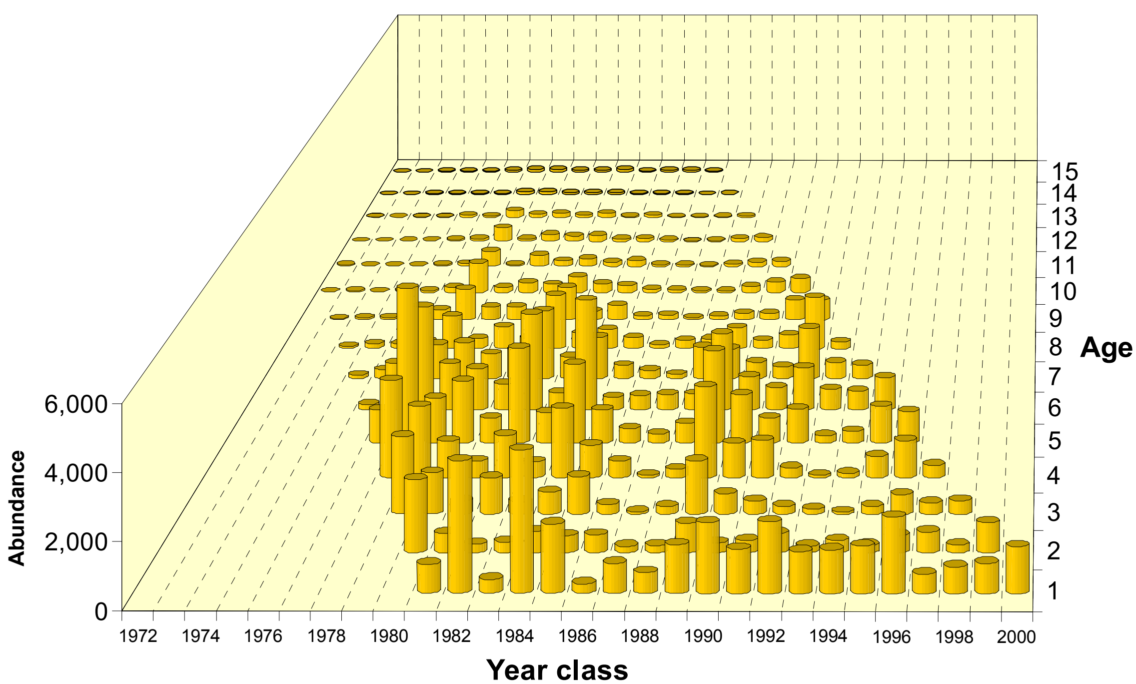
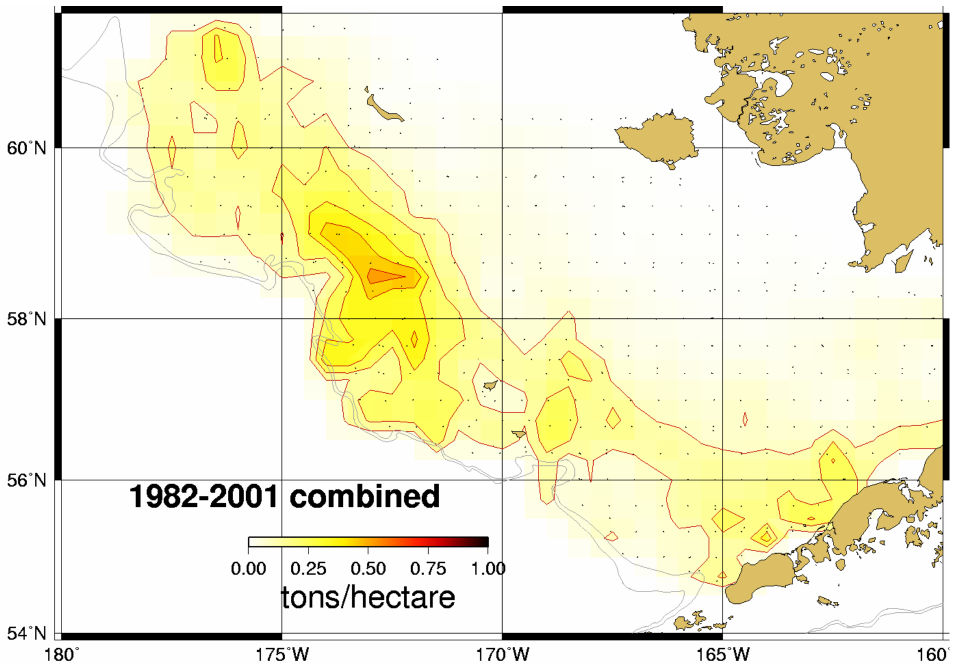


Figure 1.13. Abundance levels by age and year plotted over time (top) and by individual cohorts (year-classes) as estimated directly from the NMFS bottom-trawl surveys.



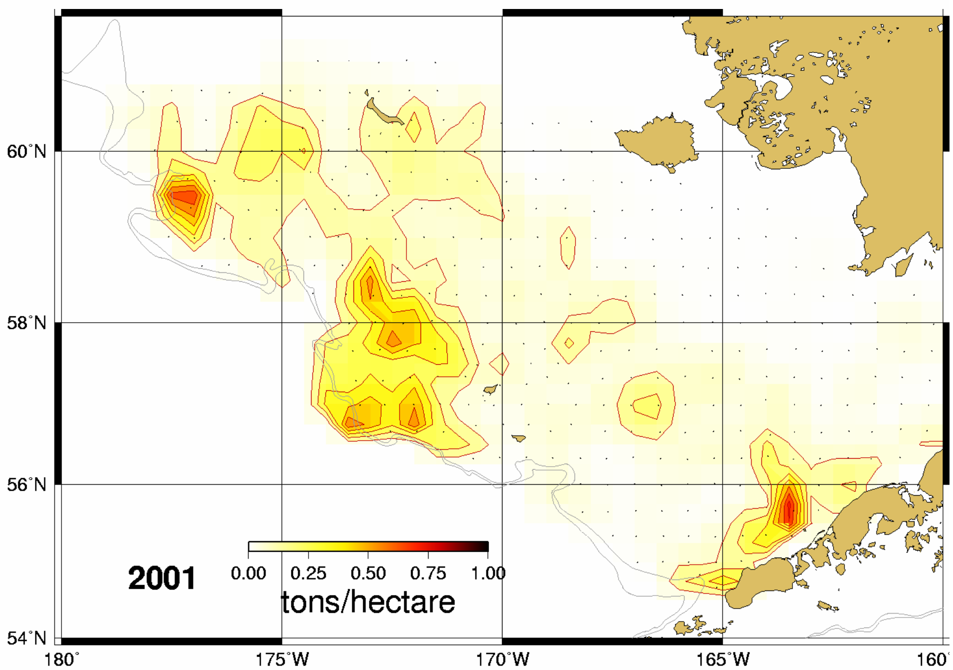


Figure 1.14. Maps showing the average walleye pollock catch-per-unit effort (1982-2001) compared to that observed during the 2001 NMFS EBS shelf bottom-trawl survey (bottom). Note that the average distribution plot contains CPUE values from the northwest portion that is not part of the "standard" survey area.

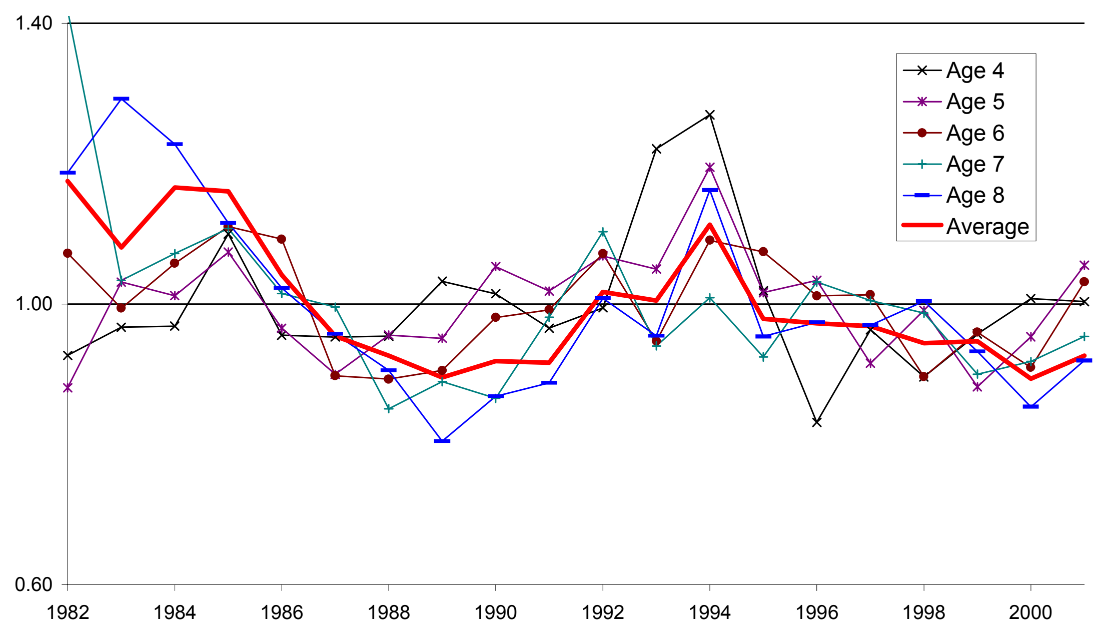


Figure 1.15. Trends in pollock average weights-at-age based on NMFS bottom trawl survey estimates, 1982-2001. Values are shown relative to their mean within each age or age group. Note that the length-weight relationship used here is constant, hence the differences are how average lengths-at-age vary over time in terms of weight.

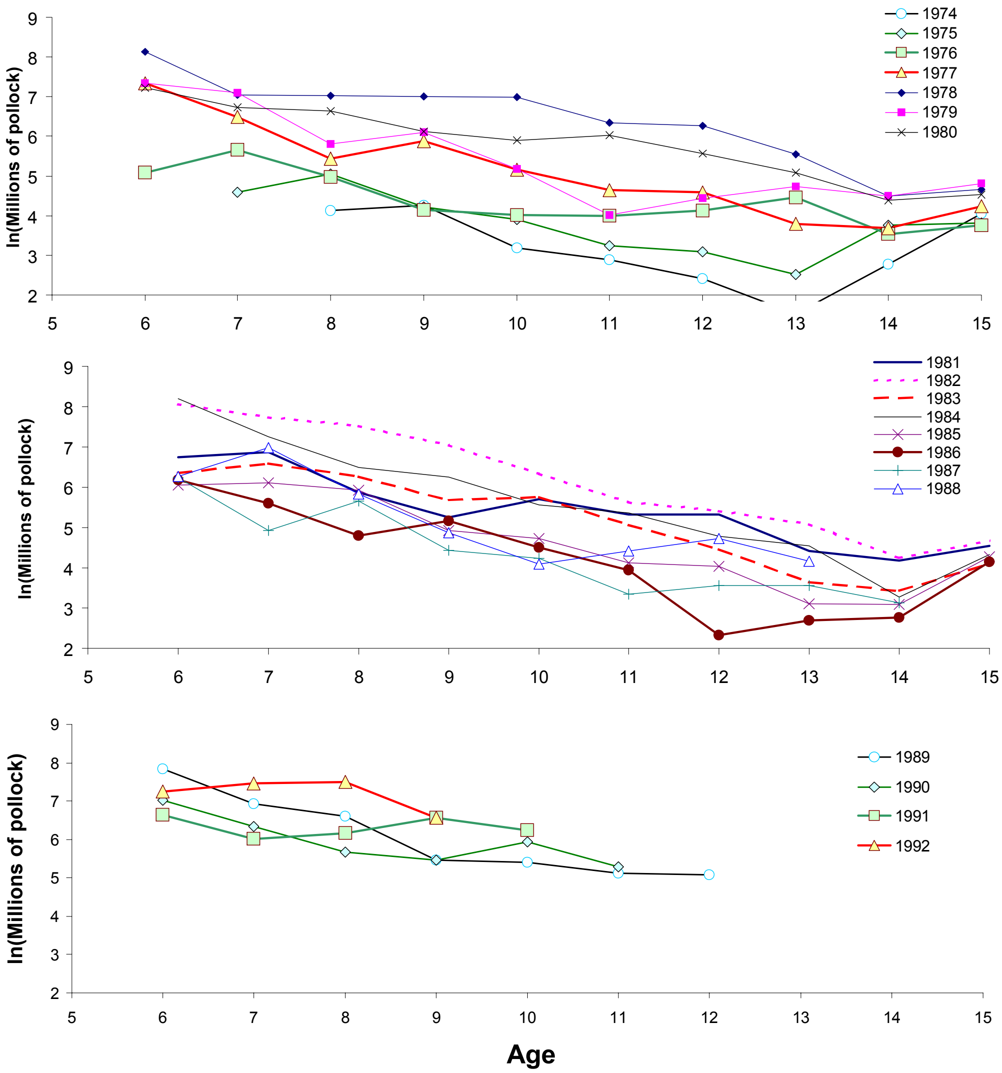


Figure 1.16. Log-abundance levels of individual EBS pollock cohorts (year-classes) as estimated directly from the NMFS bottom-trawl surveys. Estimates at age 15 were omitted since they represent age 15 and older pollock.

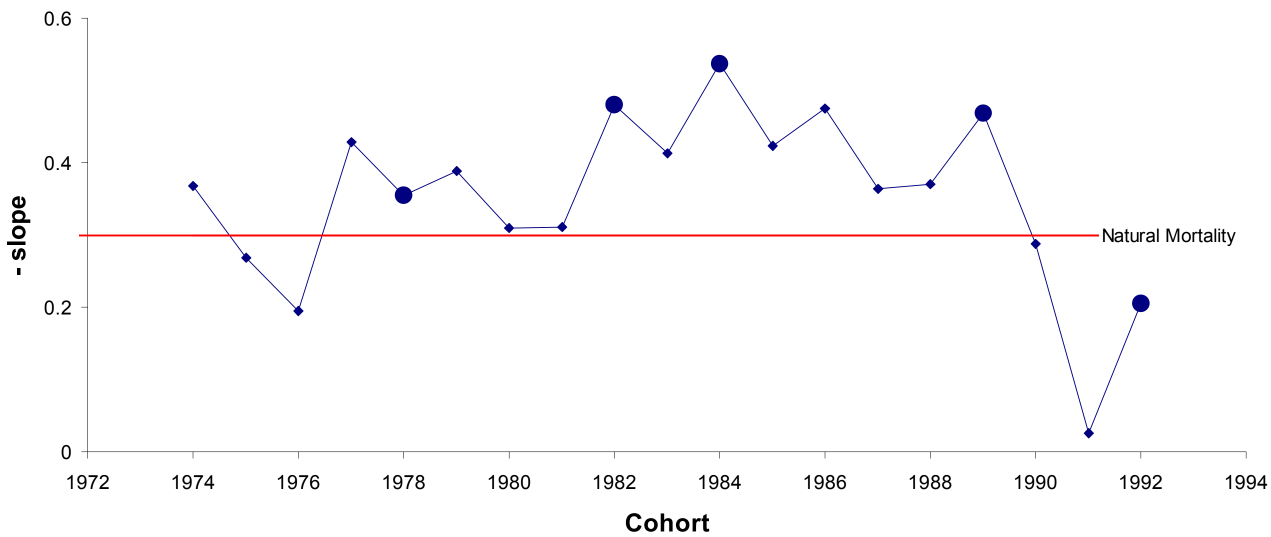


Figure 1.17. Negative slope estimates (as a proxy for total instantaneous mortality, Z) for 1974-1992 EBS pollock cohorts based on log-abundance levels as estimated directly from the NMFS bottom-trawl surveys. The assumed natural mortality rate for ages 3+ is shown as the single horizontal line. Year-classes greater than average are indicated by the larger filled circles.

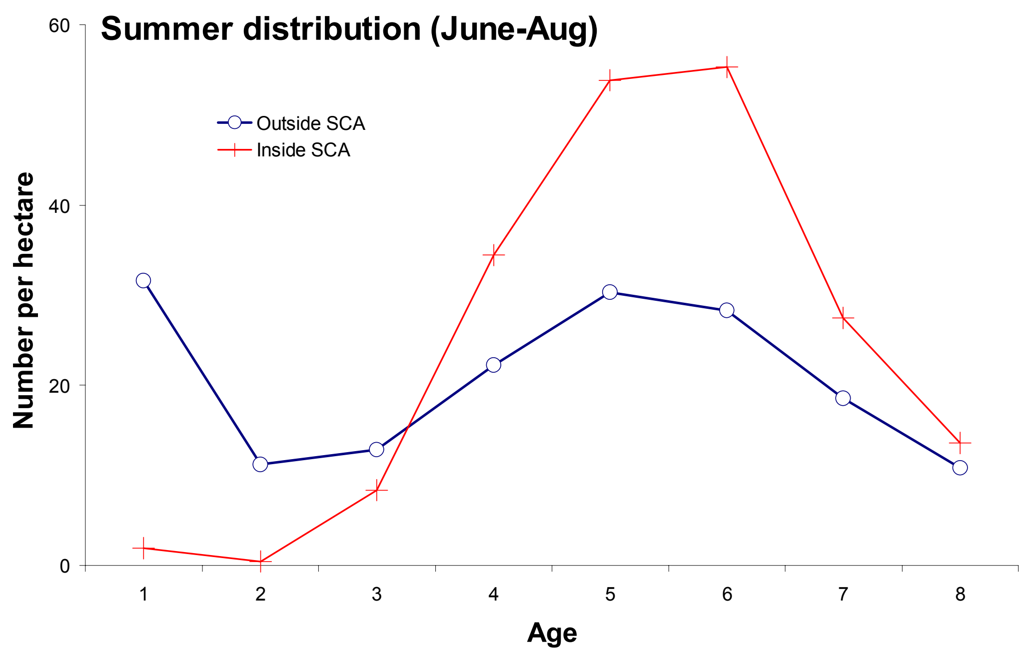


Figure 1.18. EBS pollock mean number per hectare by age based on tow-by-tow age-specific CPUE analyses of the NMFS bottom-trawl survey, 1982-1999.

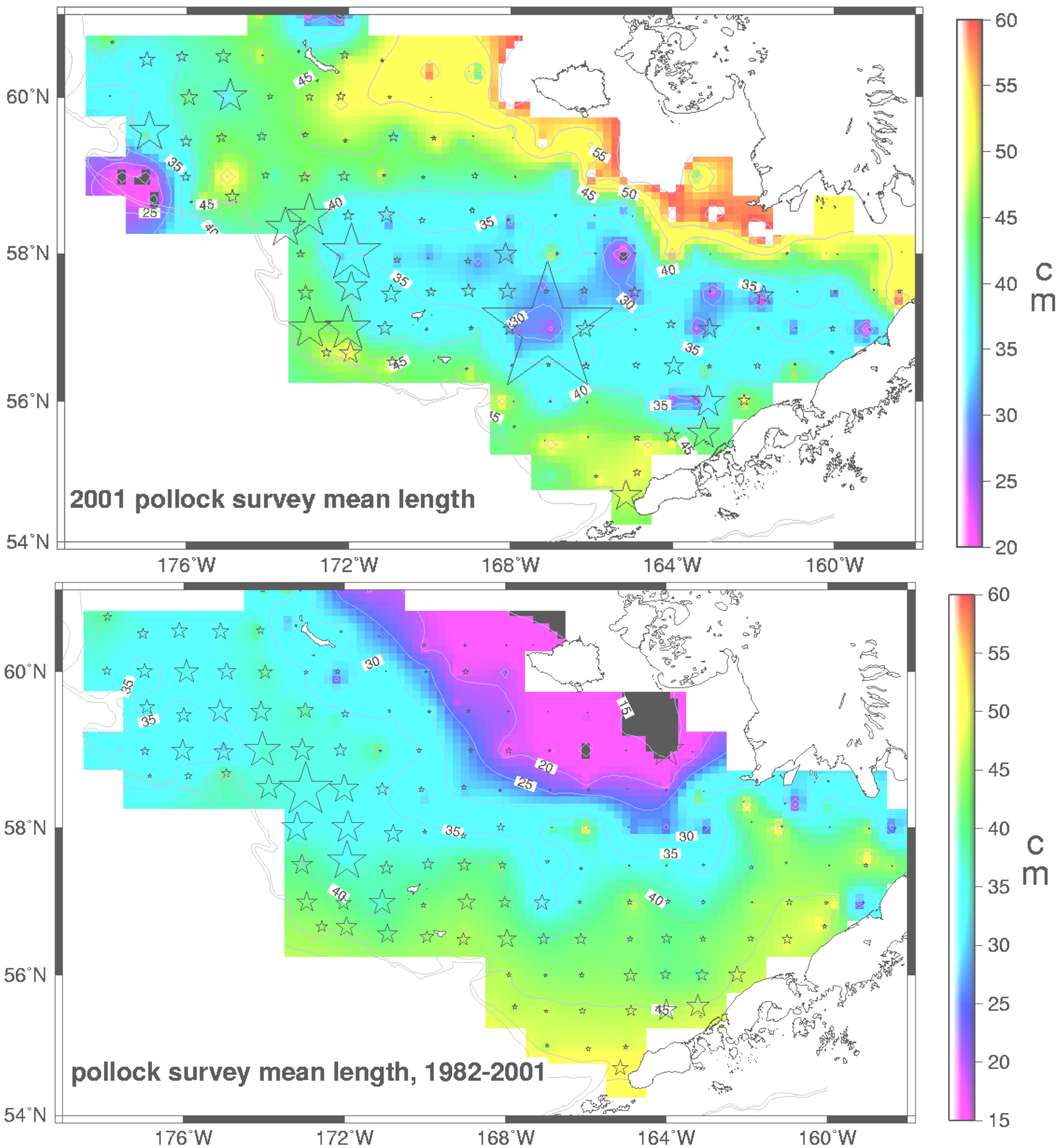


Figure 1.19. Average length distribution based on NMFS bottom trawl survey estimates for 2001 and averaged over 1982-2001. Average lengths are weighted by CPUE (catch (numbers) per unit effort). The size of the stars are proportional to the CPUE.

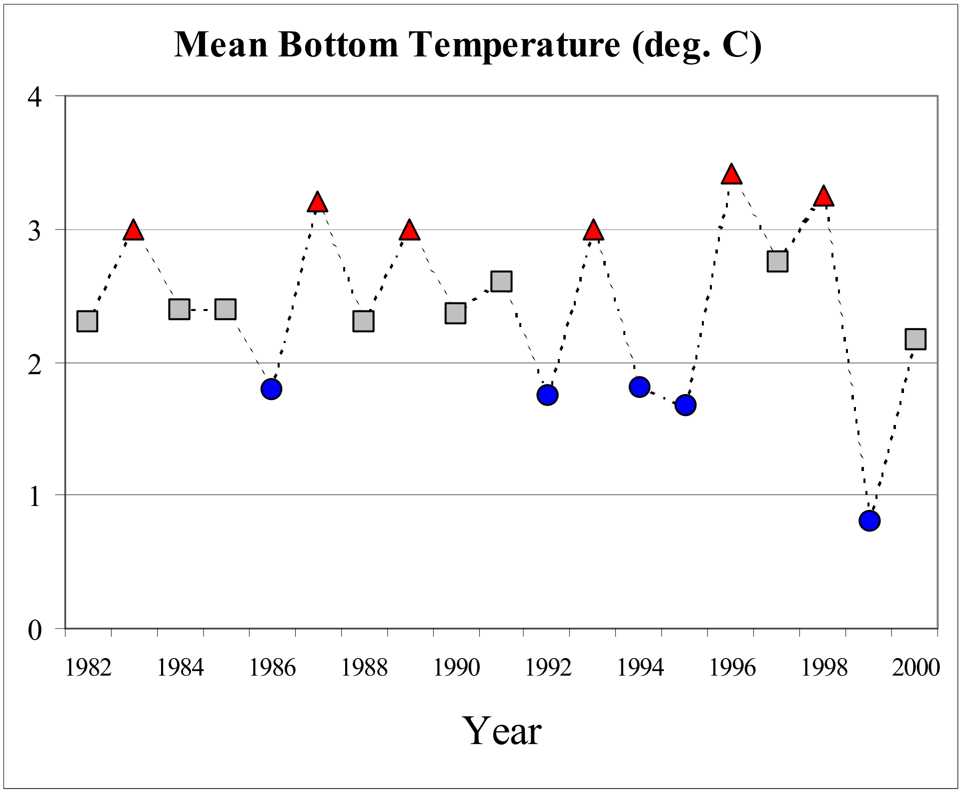


Figure 1.20. Mean summer bottom temperatures used to model bottom trawl survey pollock catchability, 1982-2000. Triangles represent years classified as “warm”, squares as “intermediate,” and circles as “cold” temperature years. (Note: these were normalized to have mean zero for use in the model).

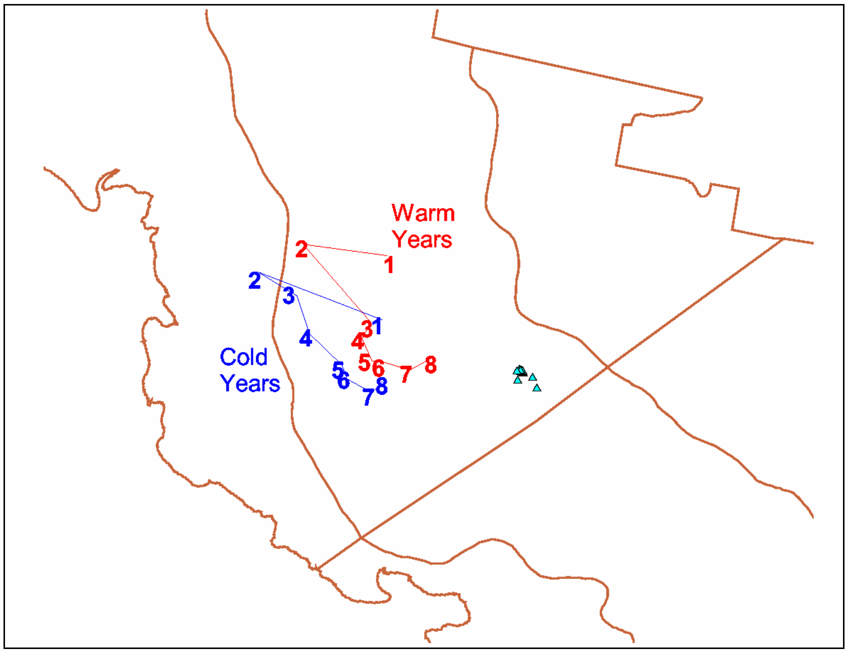


Figure 1.21. EBS pollock weighted (by number) average location by ages 1-8, 1982-2000. Lower-left line represents the average from "cold" years while the upper right line represents average location during "warm" years. Triangles represent the centers of survey operations in each year.

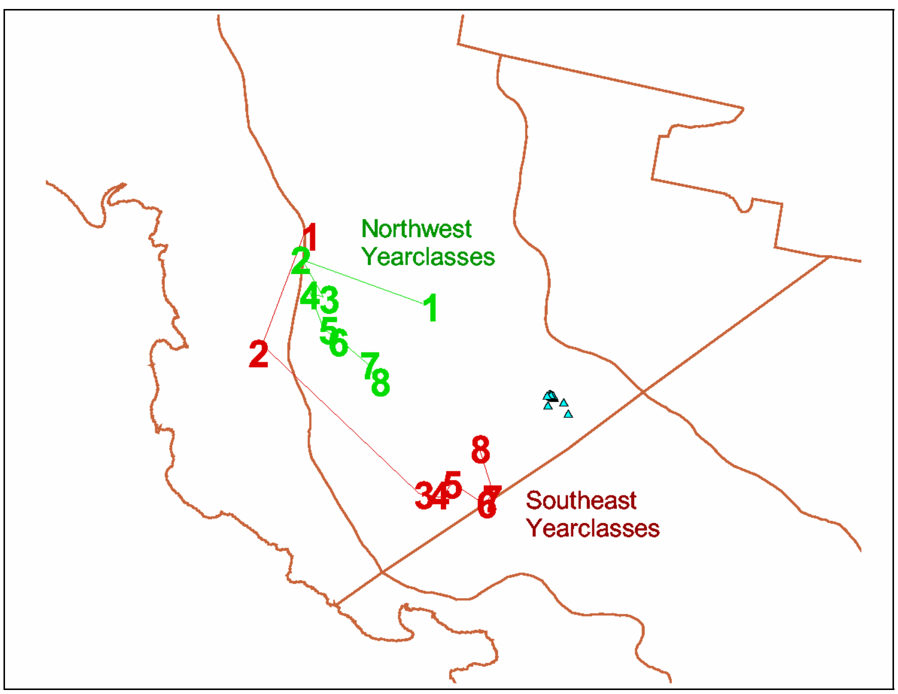


Figure 1.22. The average locations (centroids), ages 1-8 for pollock year-classes that remain concentrated in the NW area of the EBS shelf and those that shift southeastward as they age. Triangles represent the centers of survey operations in each year.

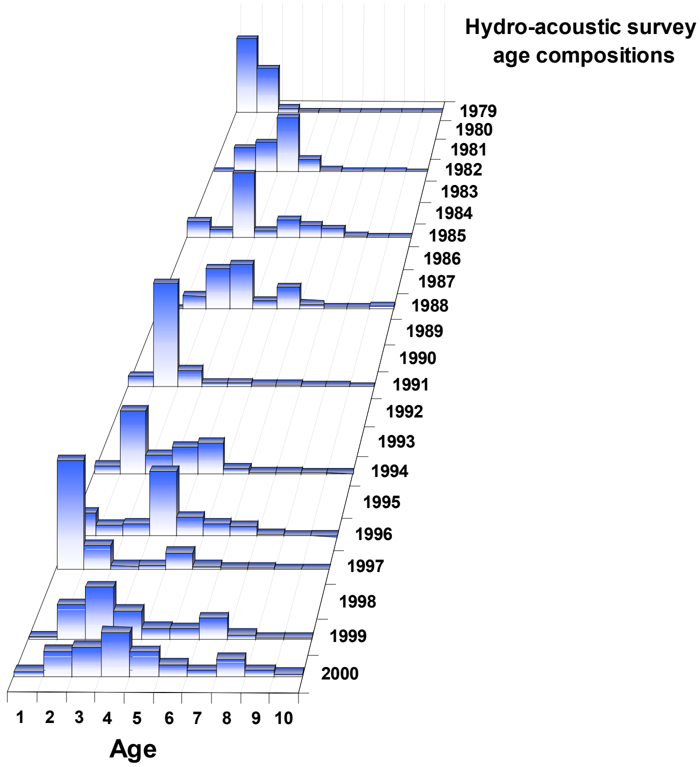


Figure 1.23. Time series of estimated proportions at age for EBS walleye pollock from the EIT surveys, 1979-2000.

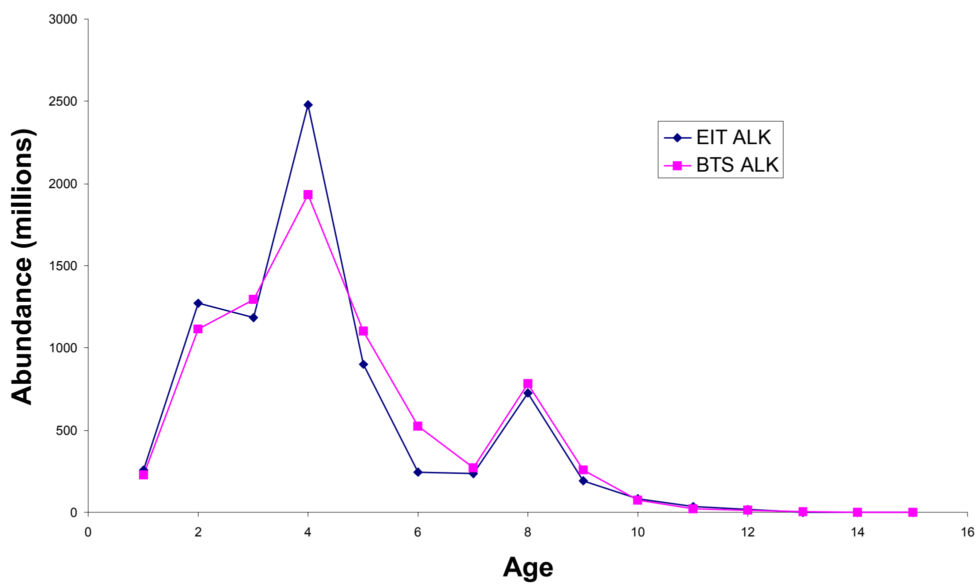


Figure 1.24. Comparison of the 2000 EIT estimates of pollock numbers-at-age based on the bottom-trawl survey age-length key (used in last year's assessment) with the final estimates based on using the age-length keys developed from the 2000 EIT survey.

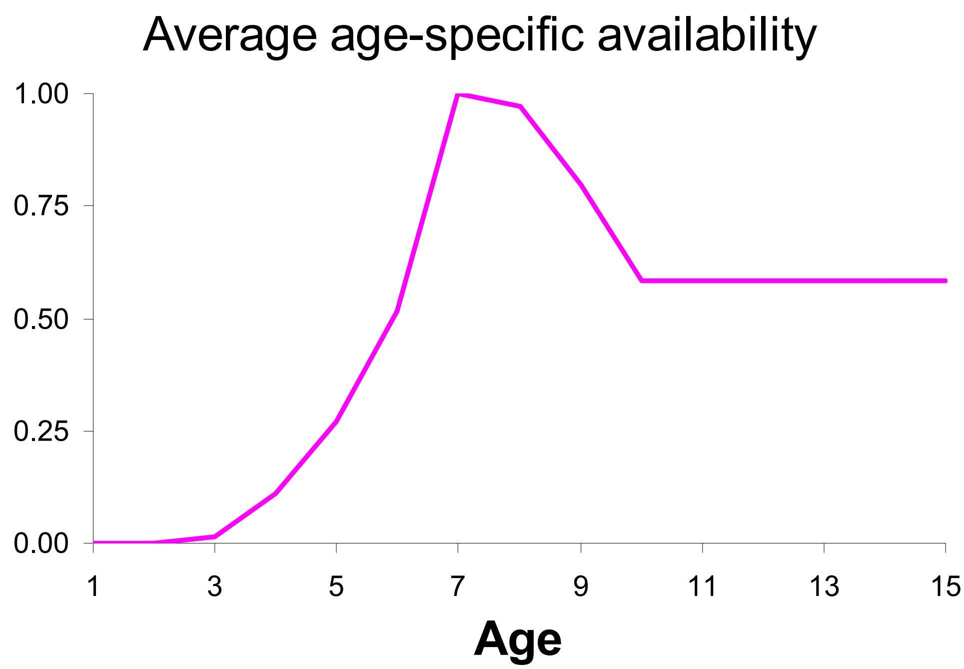


Figure 1.25. Availability/vulnerability estimates for the winter EIT shelf surveys relative to population estimates. Survey years include 2001, 2000, 1995 and 1991.

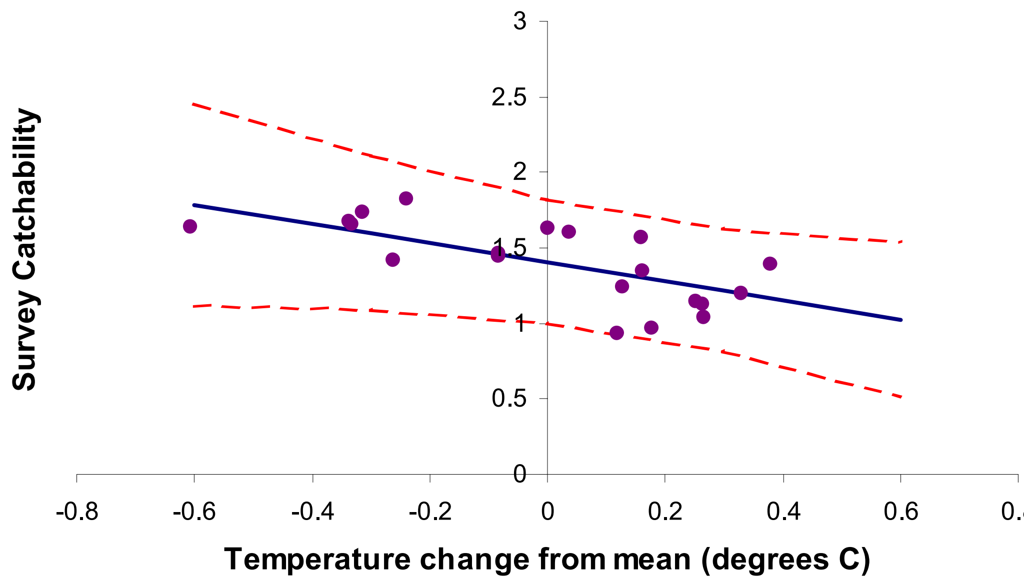


Figure 1.26. Estimated relationship between pollock bottom-trawl survey catchability and bottom temperature (normalized to have a mean value of 0) as under Model 4. Residuals relative to survey estimates area shown as points.

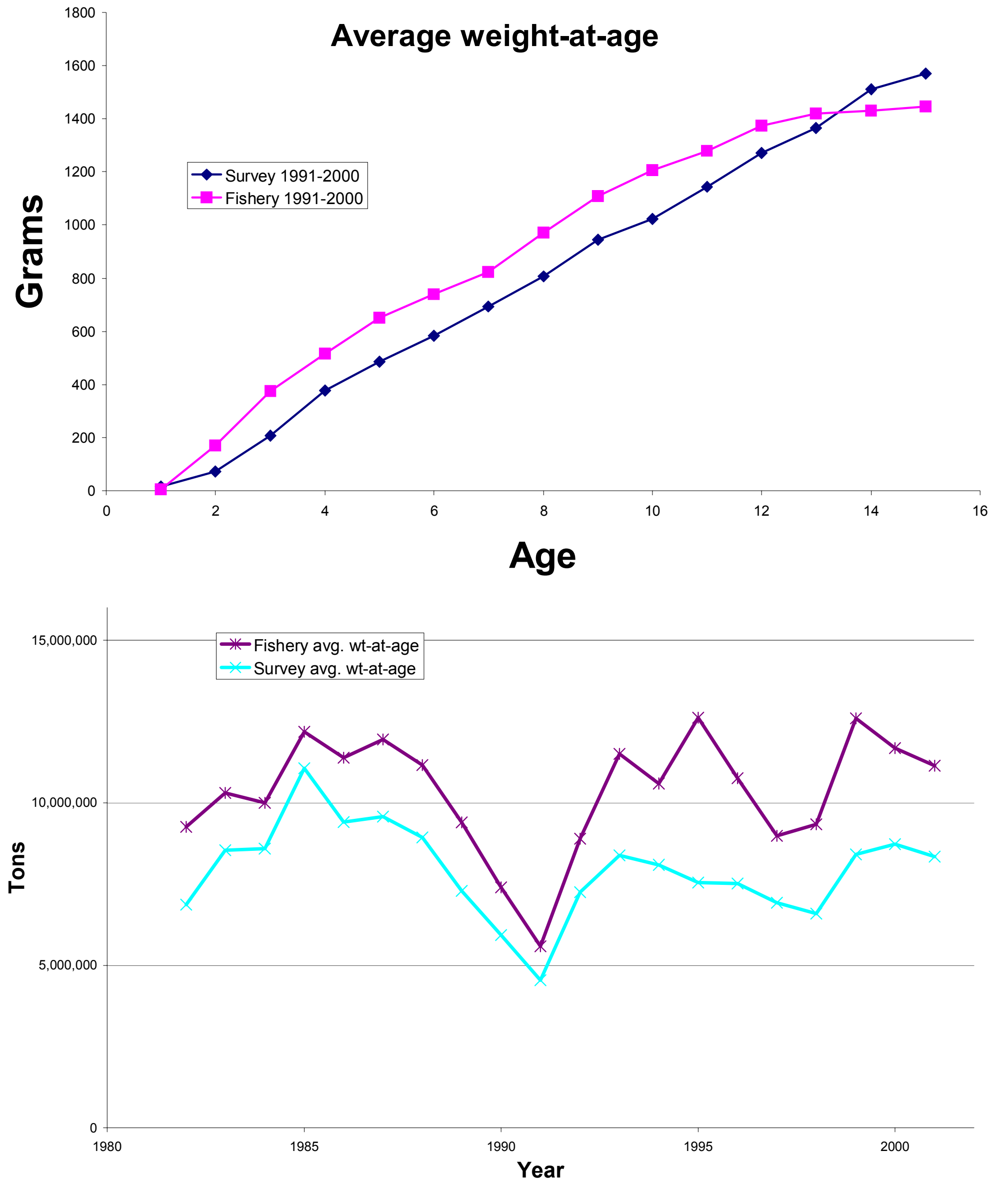


Figure 1.27. Mean EBS pollock weights-at-age as observed from NMFS bottom-trawl survey and from the EBS fishery (top panel), and the effect on estimated age-3+ biomass values (bottom panel), 1991-2000.

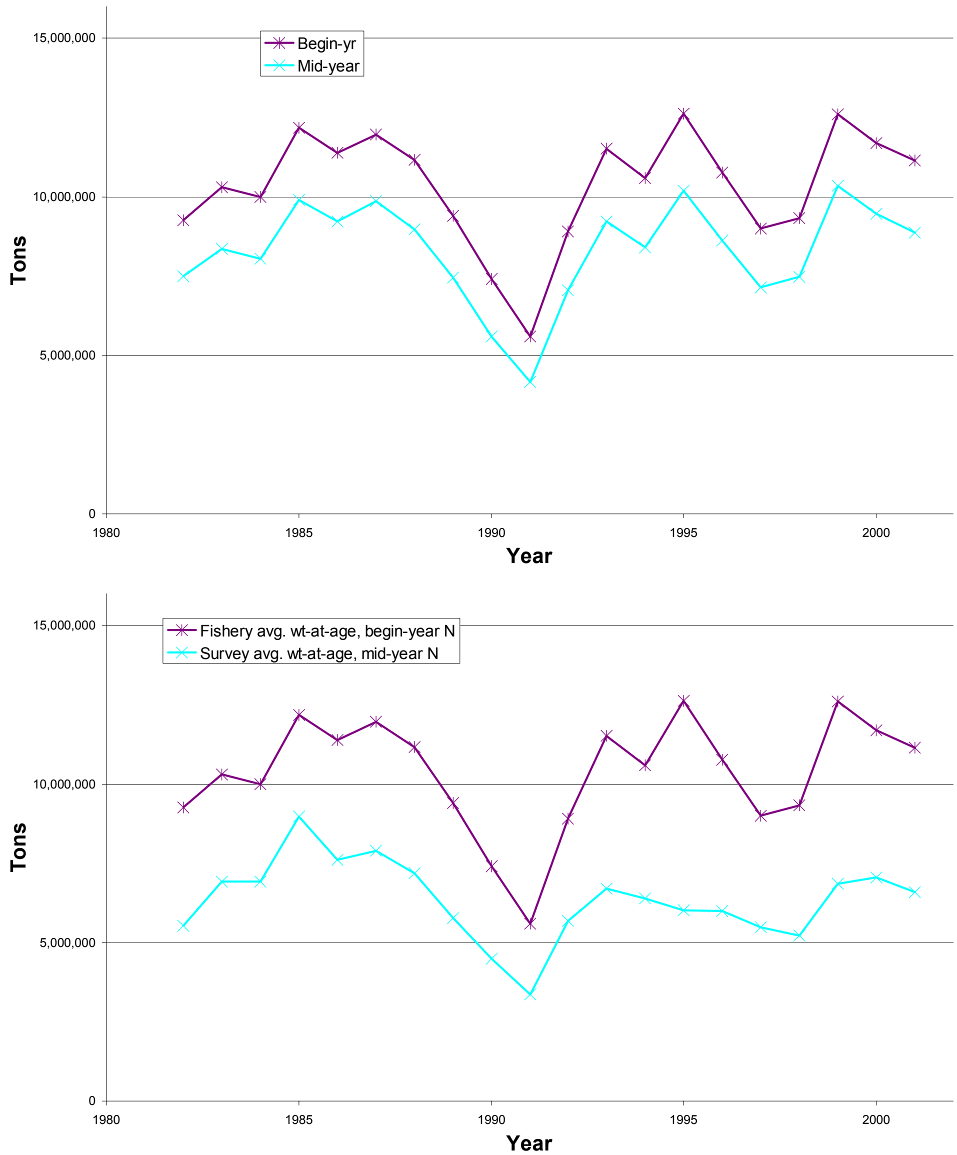


Figure 1.28. Age 3+ EBS pollock biomass computed using mean fishery-weights-at-age with begin-year numbers-at-age and mid-year numbers-at-age (top panel) and again but with mid-year numbers at age part using bottom-trawl survey average weights-at-age (bottom panel).

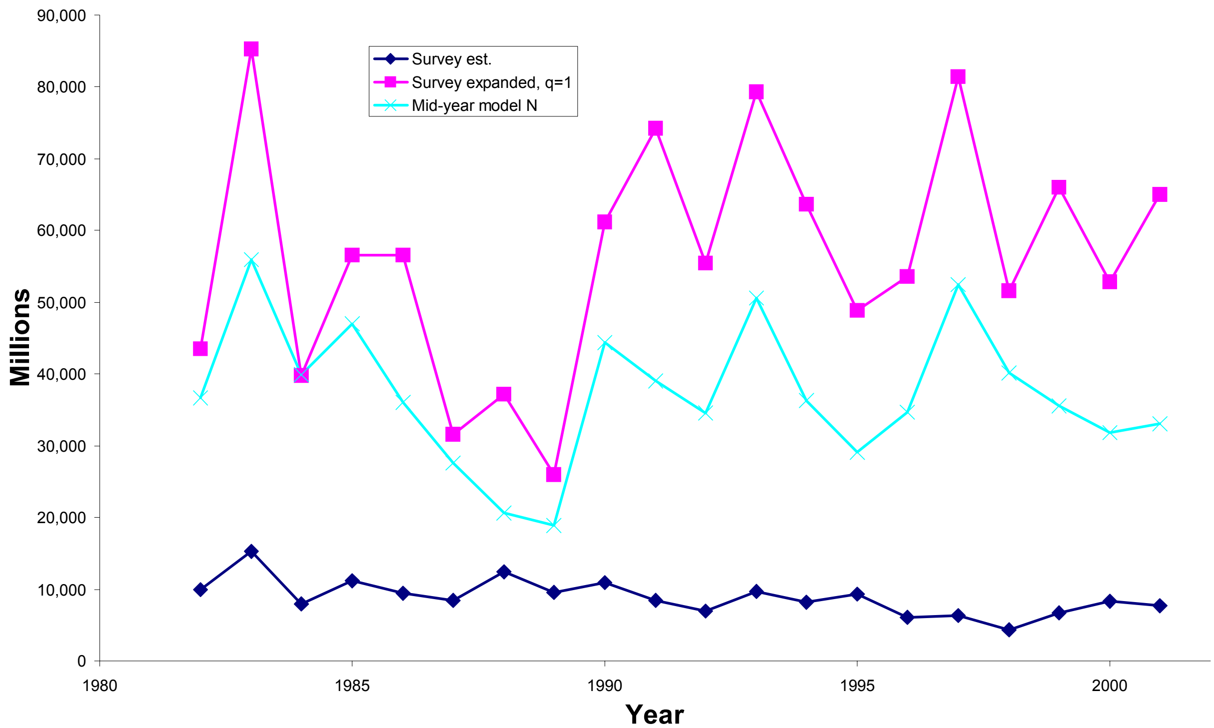


Figure 1.29. EBS pollock abundance as estimated by the bottom-trawl survey, as expanded by the age-specific availability, and as predicted by the stock assessment model.

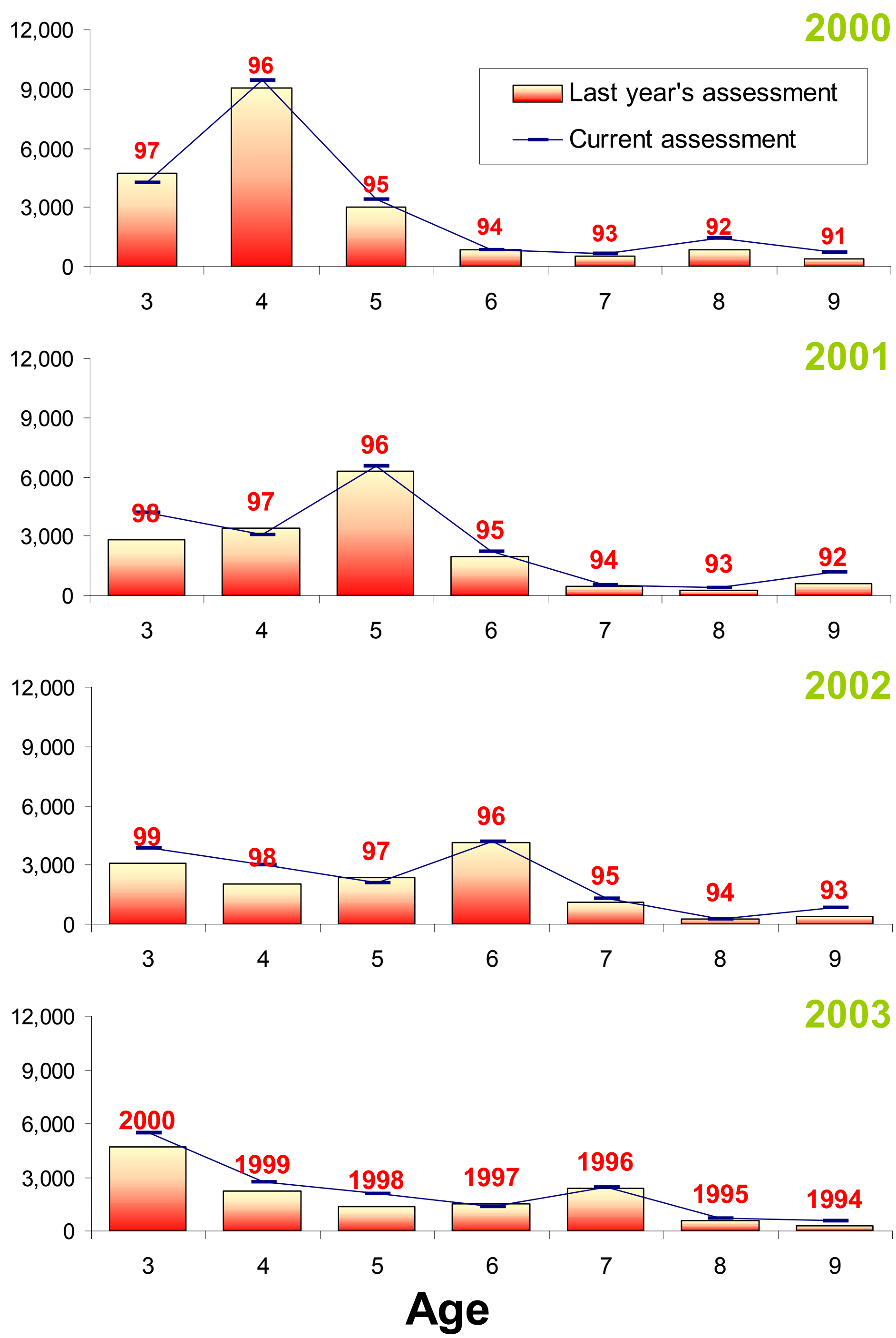


Figure 1.30. Projected EBS walleye pollock Model 1 population numbers at age compared with those presented in the last assessment (Model 1 from Ianelli *et al.*2000). Note that the "age 9" category represents all pollock age 9 and older.

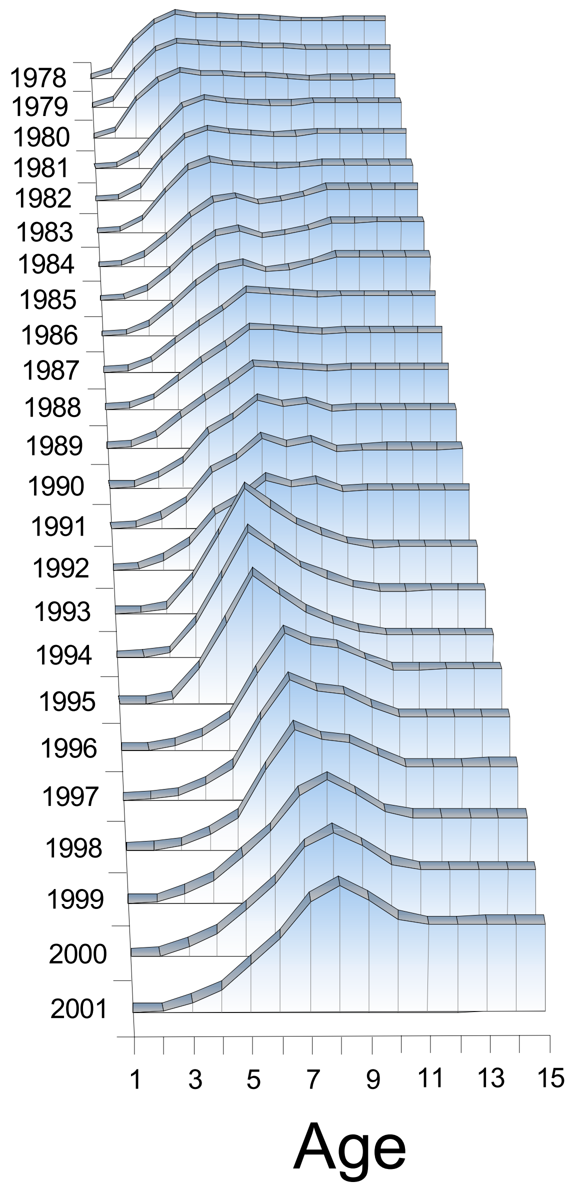


Figure 1.31. Selectivity at age estimates for the EBS walleye pollock fishery, 1978-2001 estimated for Model 1.

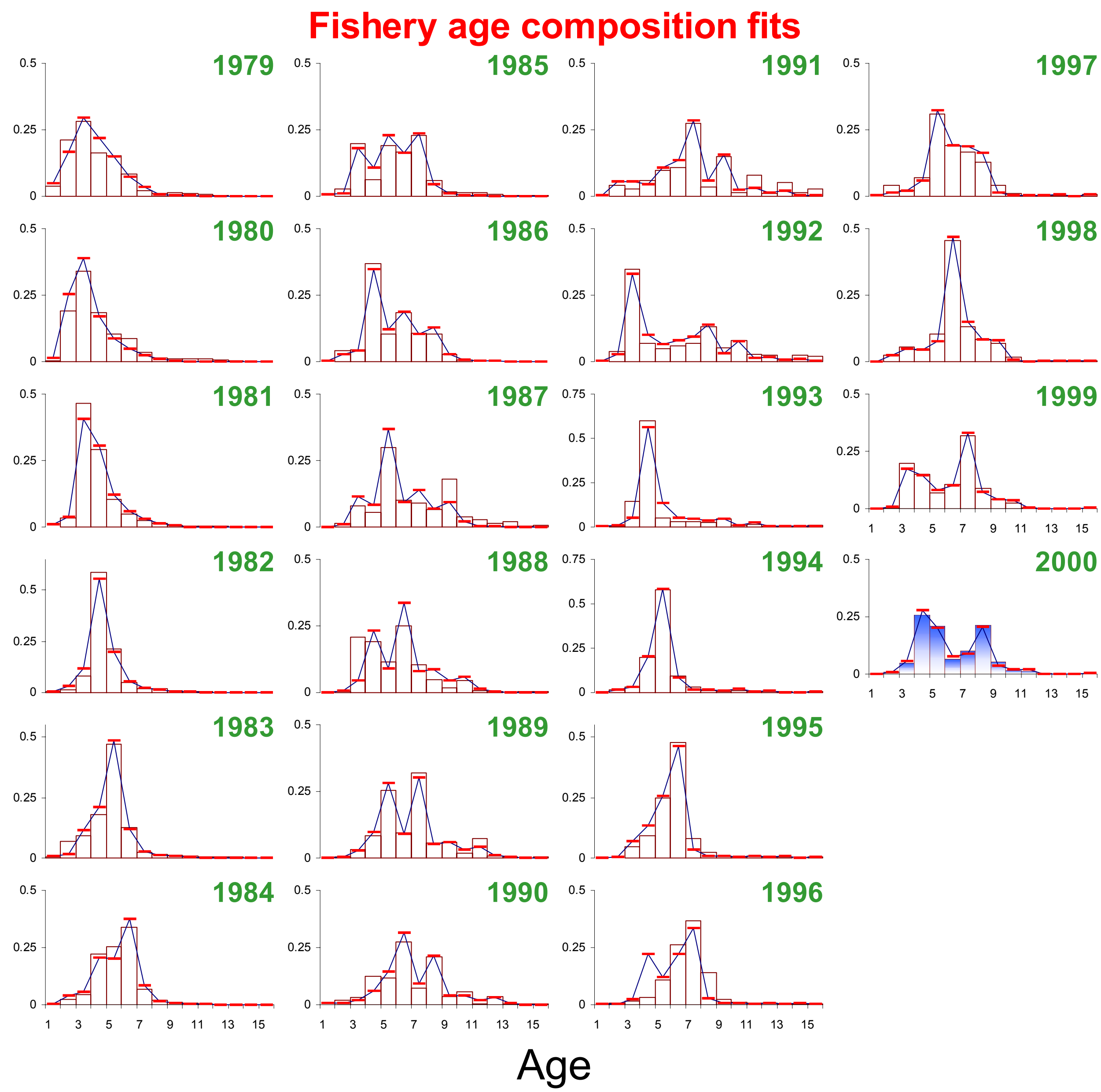


Figure 1.32. Model 1 fit to the EBS walleye pollock fishery age composition estimates (1979-2000). Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded.

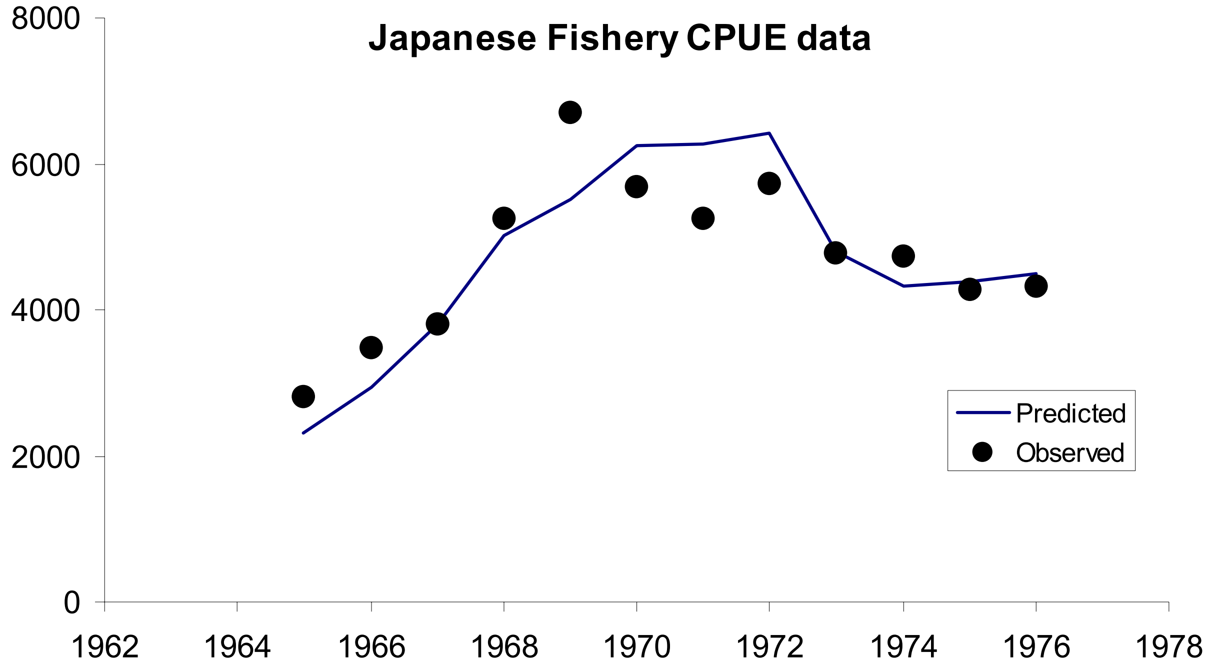
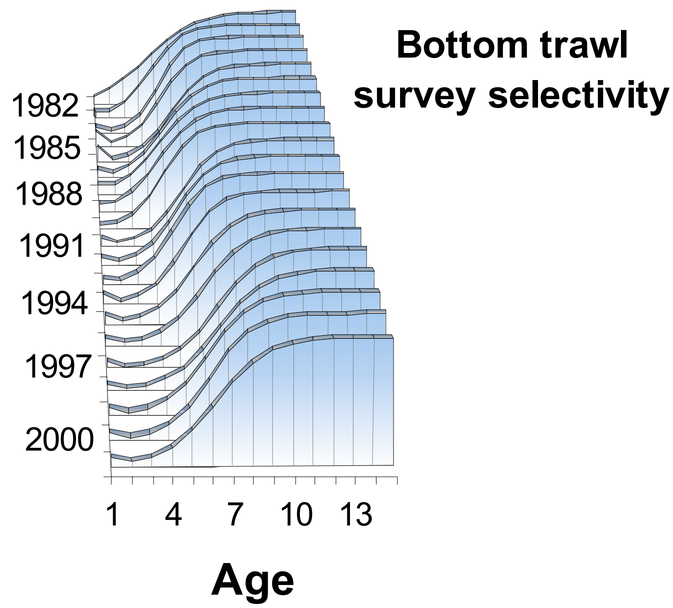


Figure 1.33. Model 1 fit to the EBS walleye pollock fishery CPUE data from Low and Ikeda (1980).



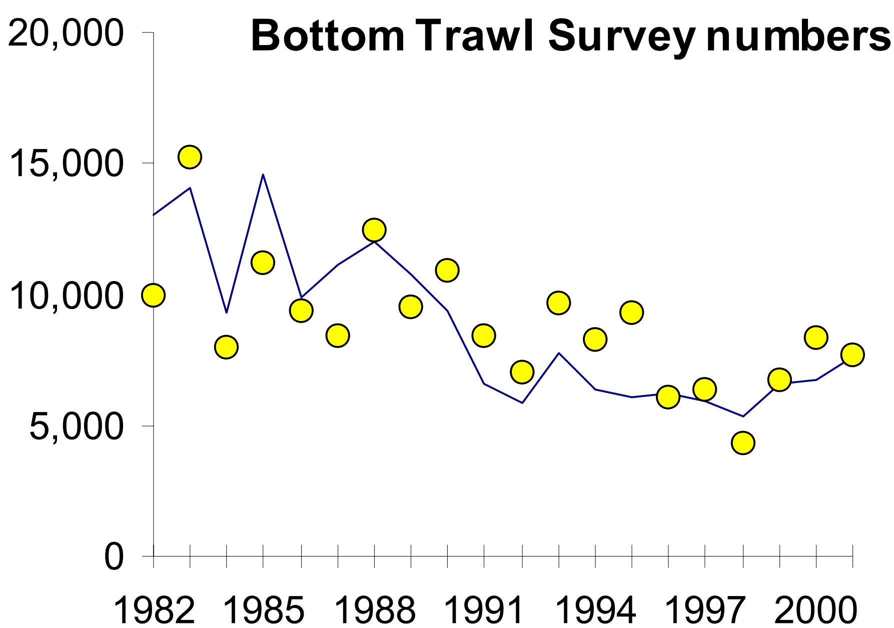


Figure 1.34. Estimates of bottom-trawl survey numbers (lower panel) and selectivity-at-age (with maximum value equal to 1.0) over time (upper panel) for EBS walleye pollock, Model 1.

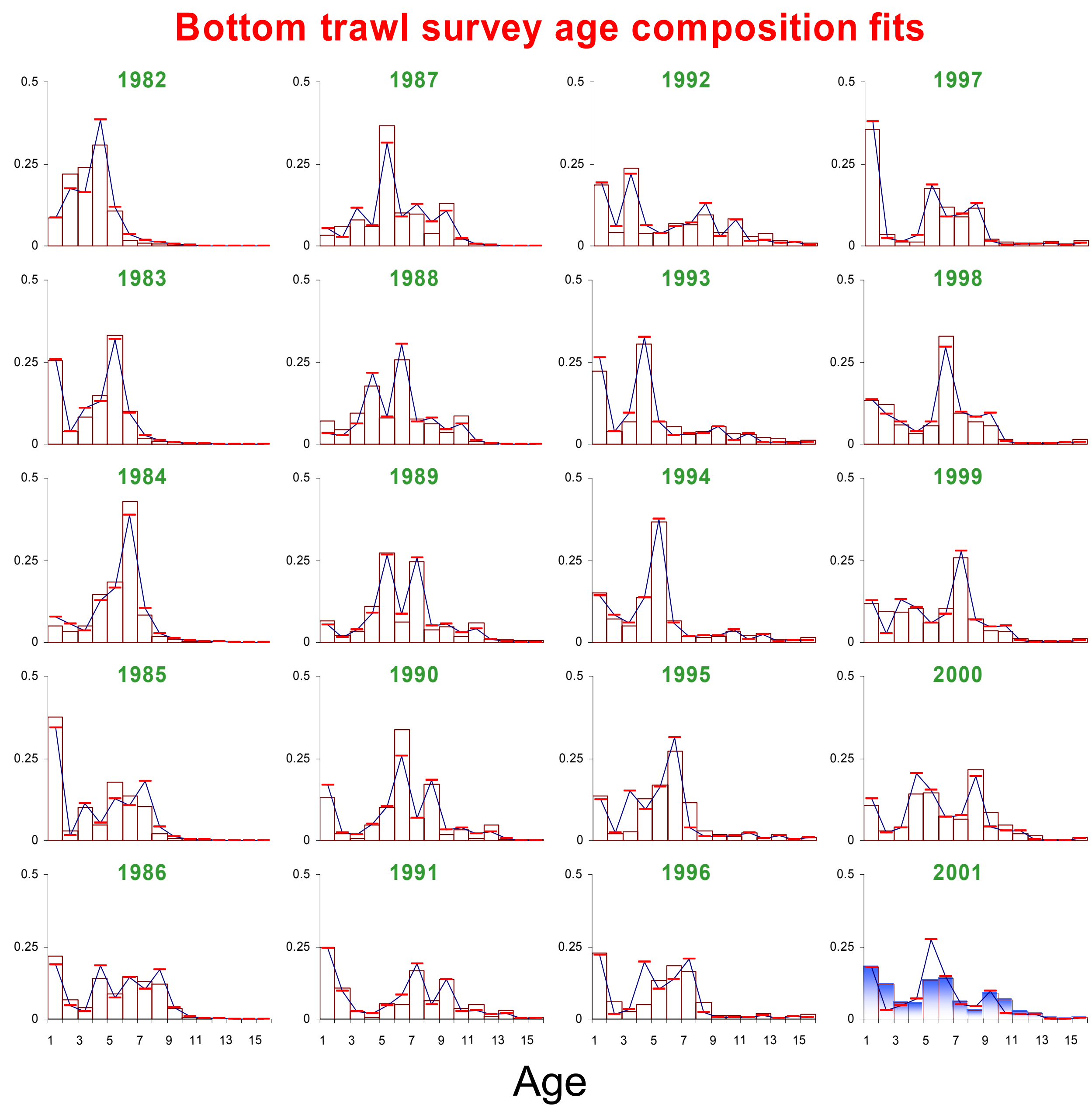
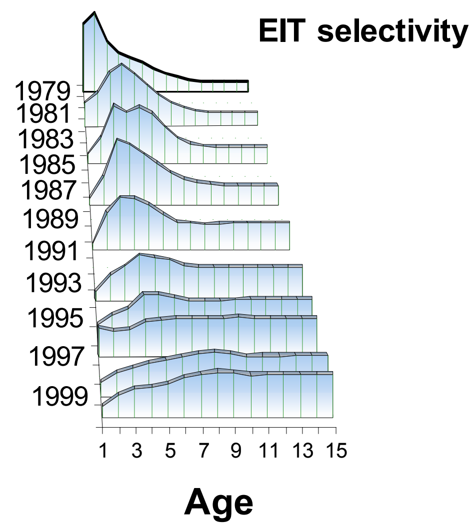


Figure 1.35. Model 1 fit to the bottom trawl survey age composition data (proportions) for EBS walleye pollock. Lines represent model predictions while the vertical columns represent the data. Data new to this assessment are shaded (2001).



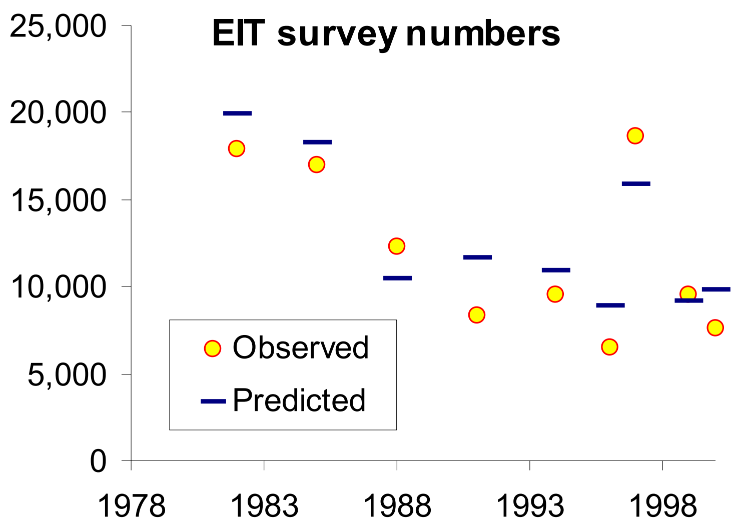


Figure 1.36. Model 1 estimates of EIT survey numbers (lower panel) and selectivity-at-age (with mean value equal to 1.0) over time (upper panel) for EBS walleye pollock. Note that the 1979 value (observed=115,424; predicted=49,326) are not plotted.

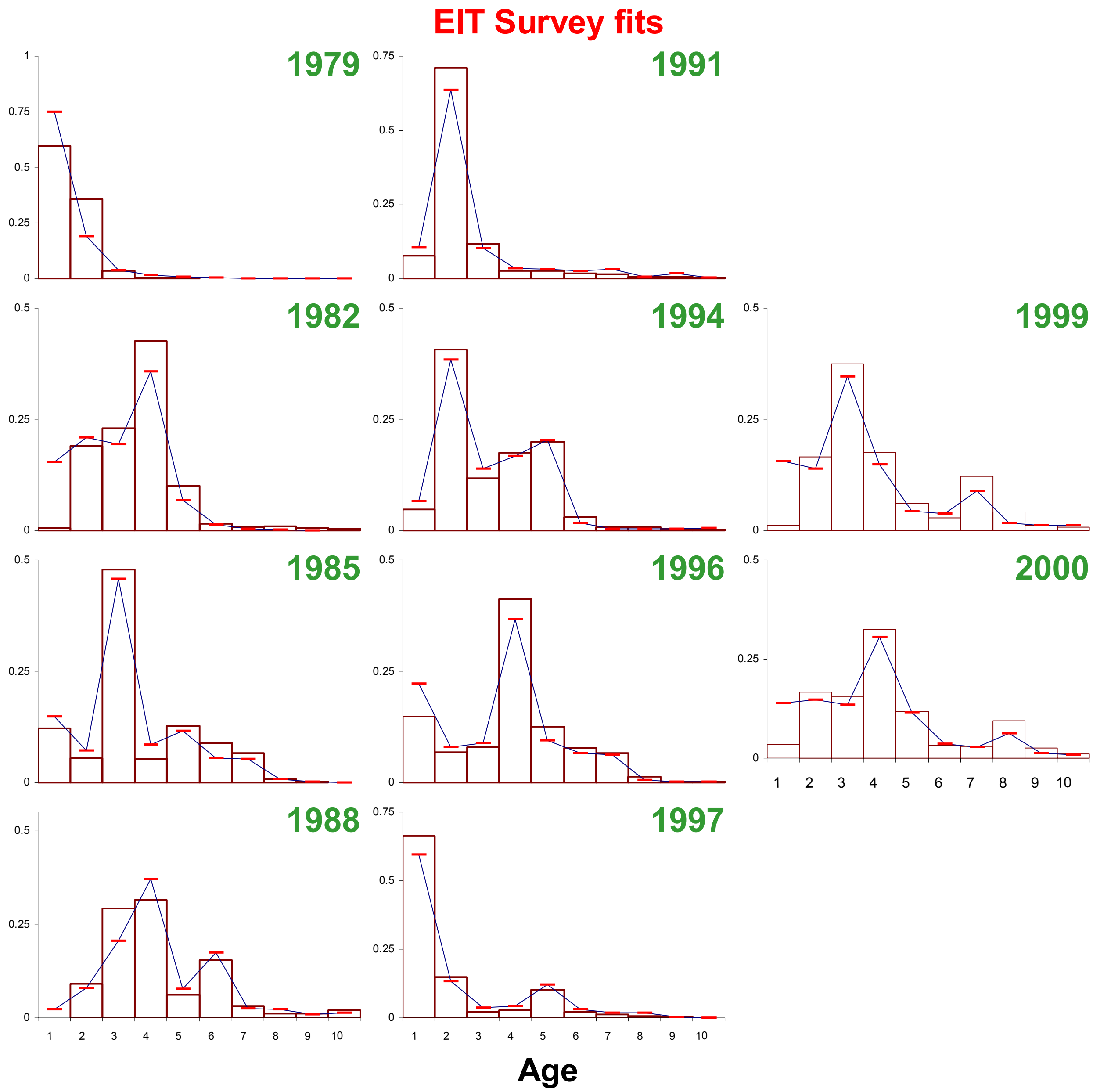


Figure 1.37. Model 1 fit to the EIT survey EBS walleye pollock age composition data (proportions). Lines represent model predictions while the vertical columns represent the data.

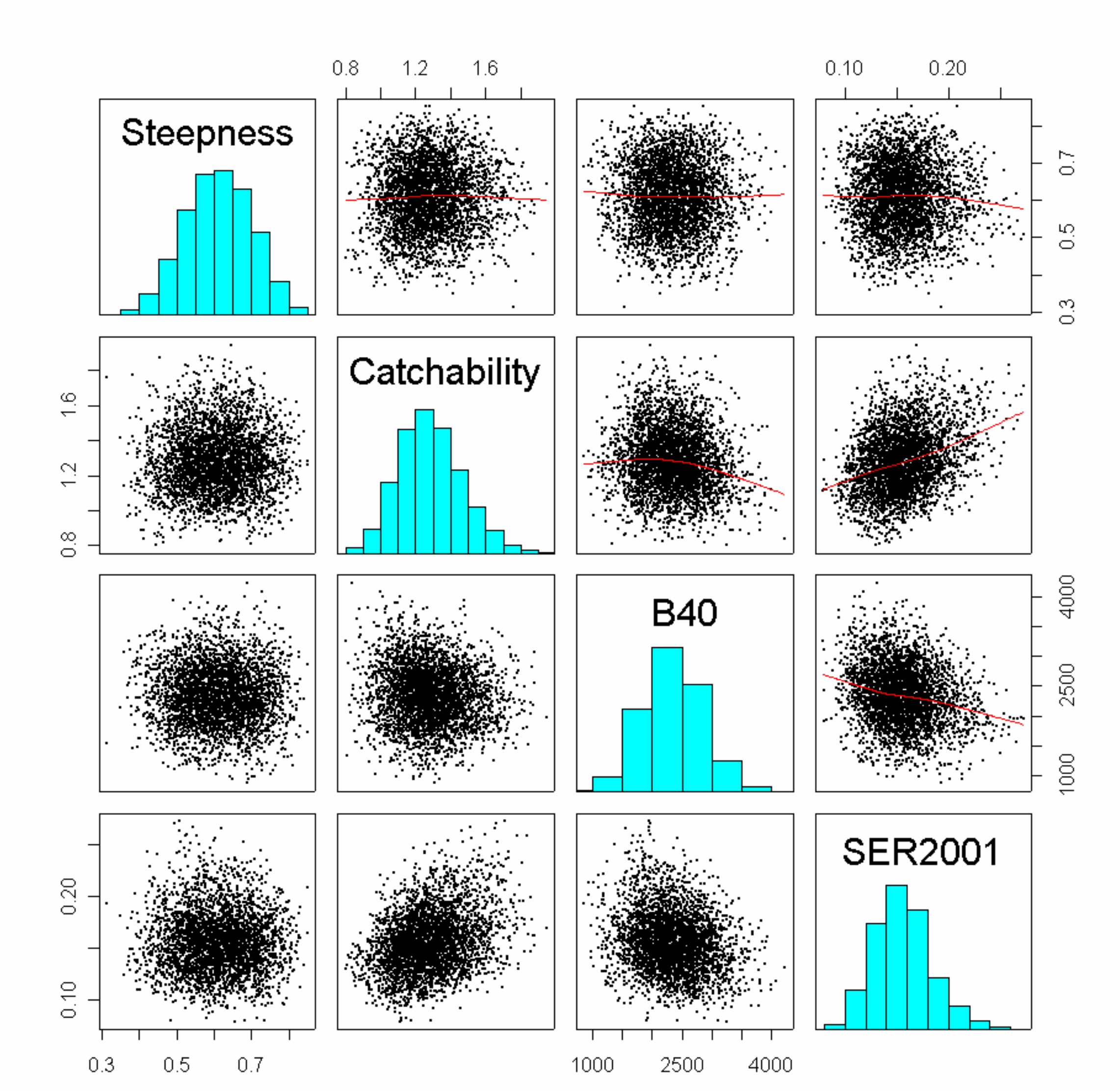


Figure 1.38. Pair-wise marginal plots of selected parameters of the joint posterior distribution based on a thinned MCMC chain used for integration.

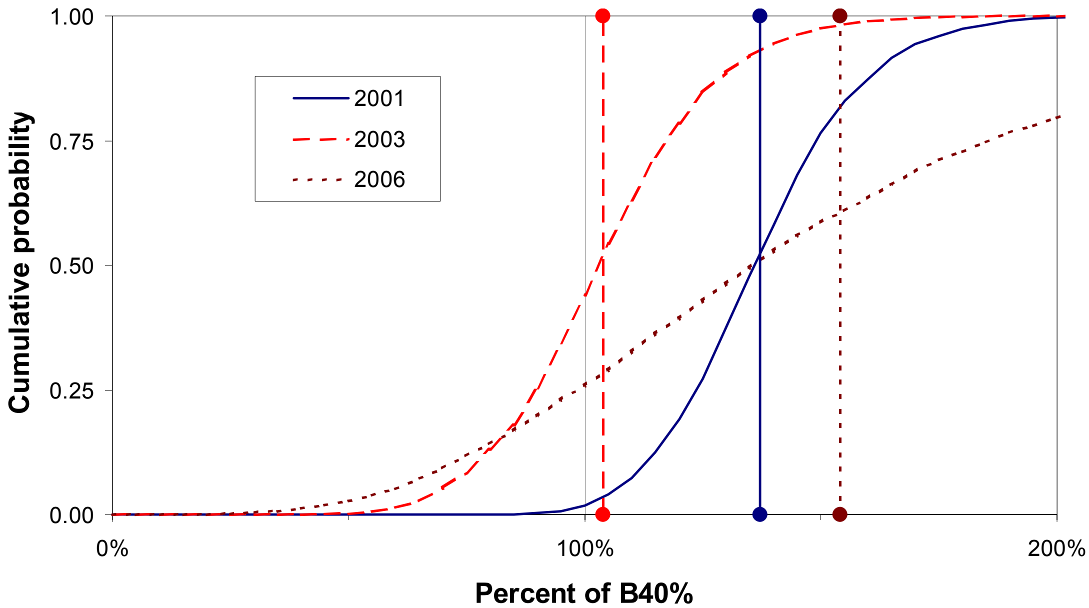


Figure 1.39. Cumulative probability that projected female spawning biomass levels will drop below $B_{40\%}$ based on a fixed constant catch levels of 1.3 million tons. Marginal distributions the full joint posterior distribution based on a thinned MCMC chain used for integration. Corresponding expected values (means) are shown by the vertical lines terminated with closed circles.

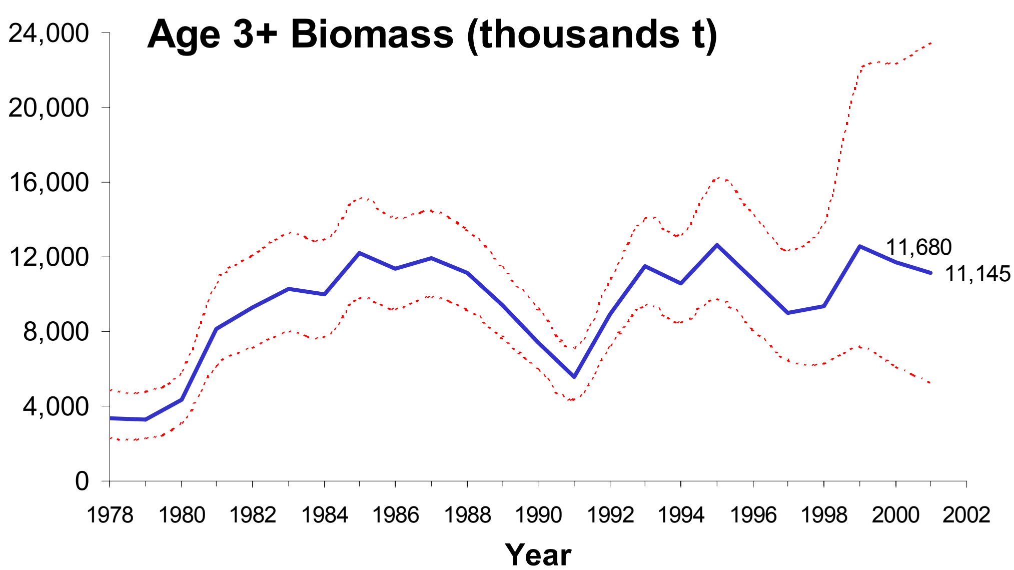


Figure 1.40. Estimated age 3+ EBS walleye pollock biomass under Model 1, 1978-2001. Approximate upper and lower 95% confidence limits are shown by dashed lines. Note: average fishery weights-at-age are applied to begin-year numbers-at-age to compute these values.

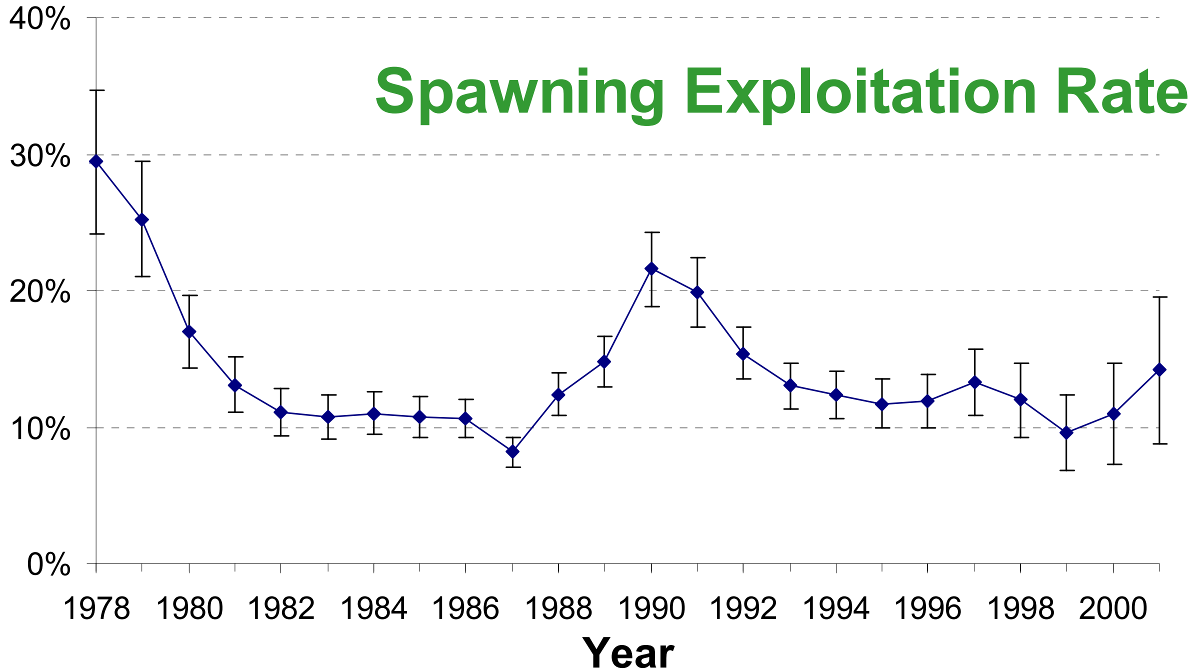


Figure 1.41. Estimated spawning exploitation rate (computed as the percent removals of spawning females each year) for EBS walleye pollock, Model 1. Error bars represent two standard deviations from the estimate.

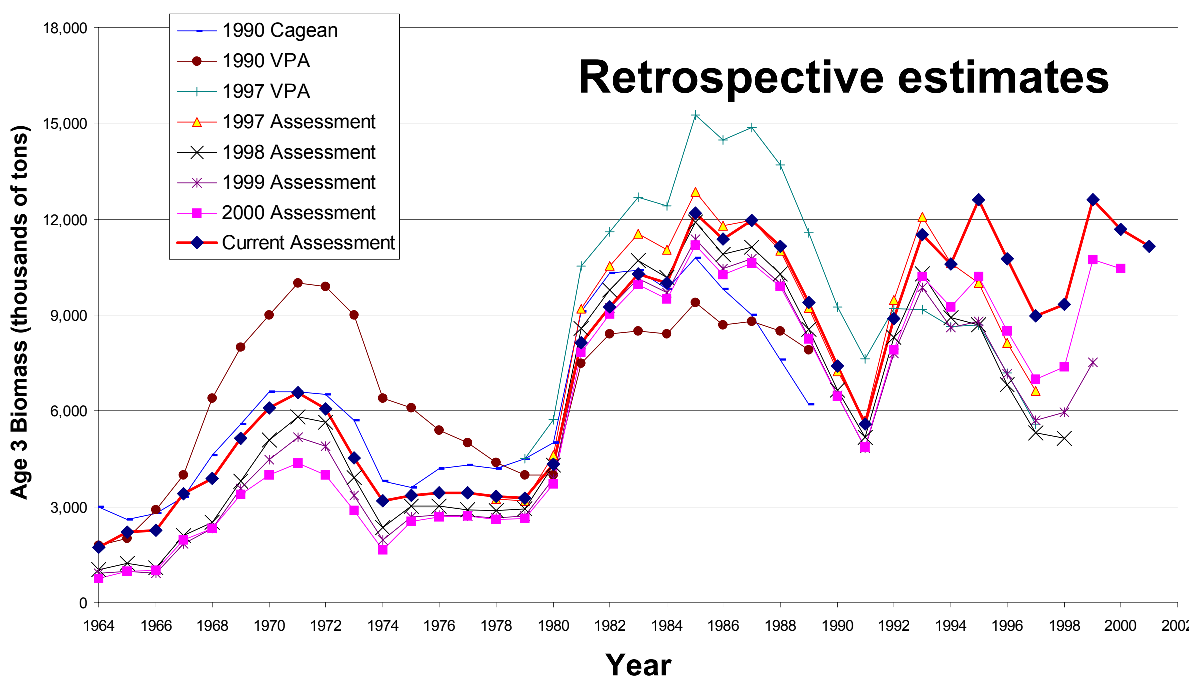


Figure 1.42. Comparison of the current assessment results with past assessments of begin-year EBS age-3+ pollock biomass.

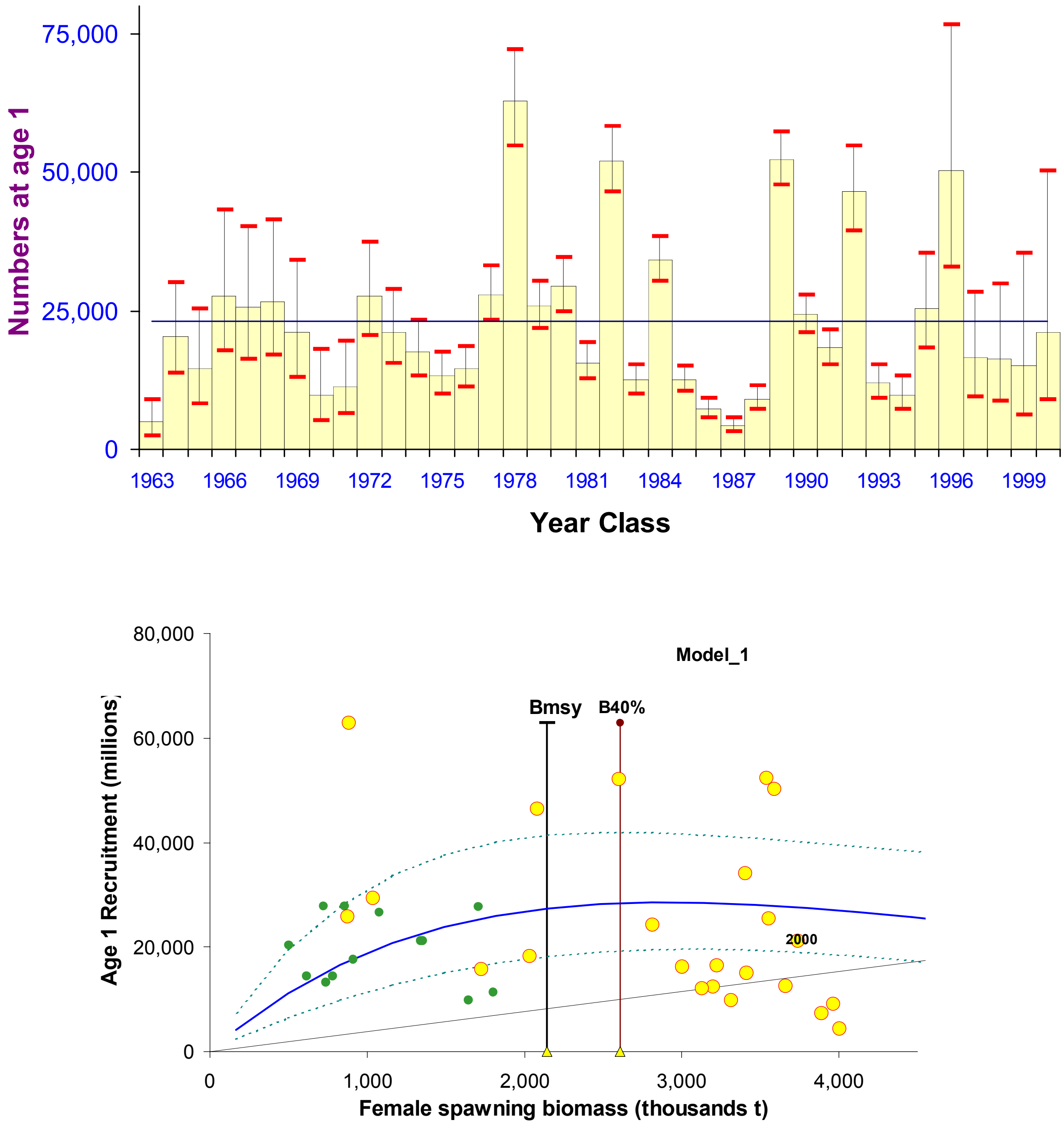
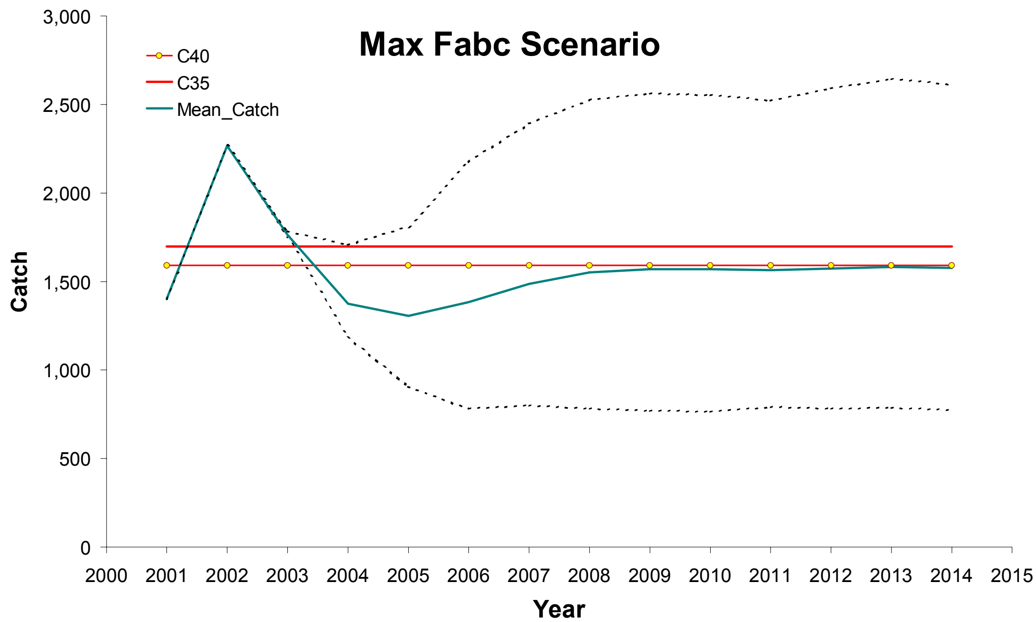


Figure 1.43. Year-class strengths by year (as age-1 recruits, upper panel) and relative to female spawning biomass (thousands of tons, lower panel) for EBS walleye pollock, Model 1. Solid line in upper panel represents the mean recruitment for all years since 1964. Vertical lines in lower panel indicate B_{msy} and $B_{40\%}$ level, curve represents fitted stock-recruitment relationship with diagonal representing the replacement lines with no fishing. Dashed lines represent lower and upper 95% confidence limits about the curve.



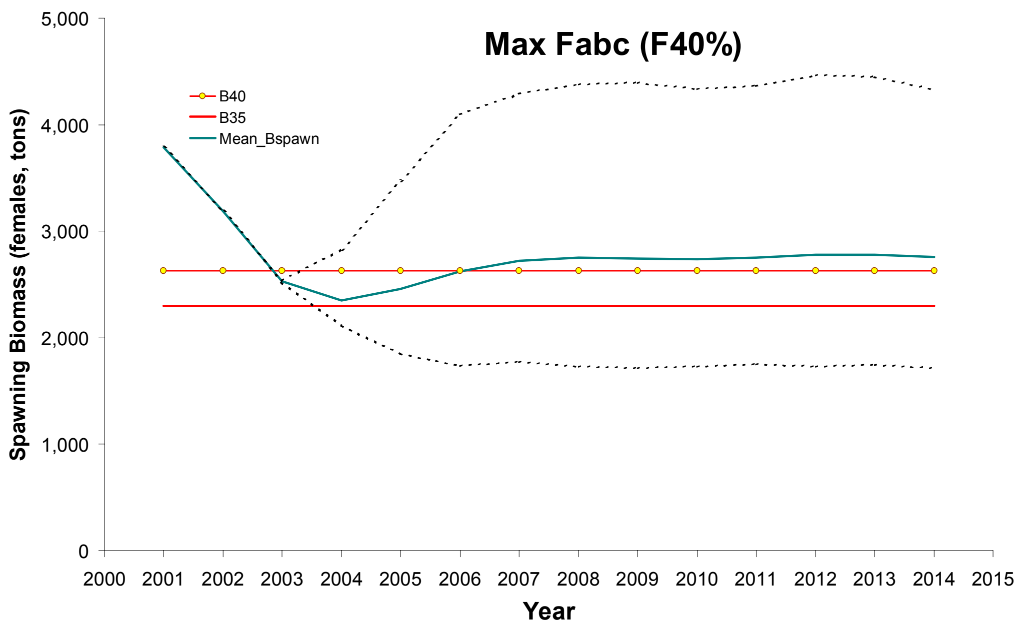


Figure 1.44. Projected EBS walleye pollock **yield** (top) and **Female spawning biomass** (bottom) relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1. $B_{40\%}$ is computed from average recruitment from 1978-2001. Future harvest rates follow the guidelines specified under Scenario 1, max F_{ABC} assuming $F_{ABC} = F_{40\%}$.

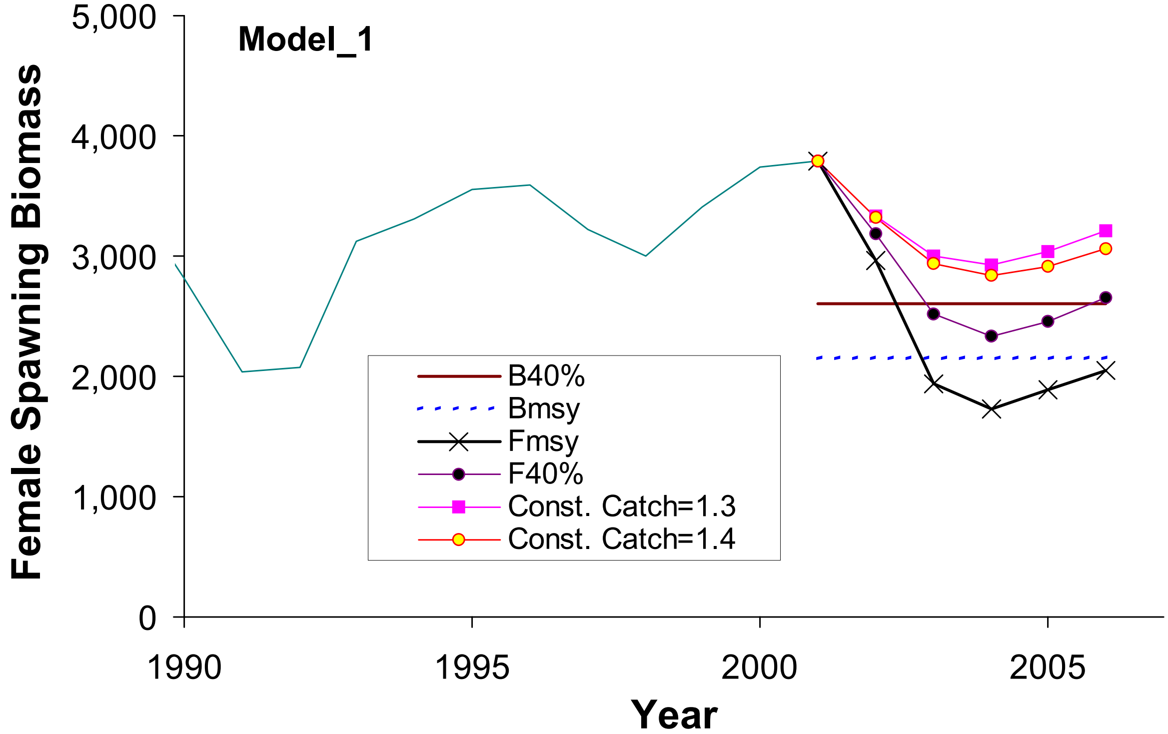
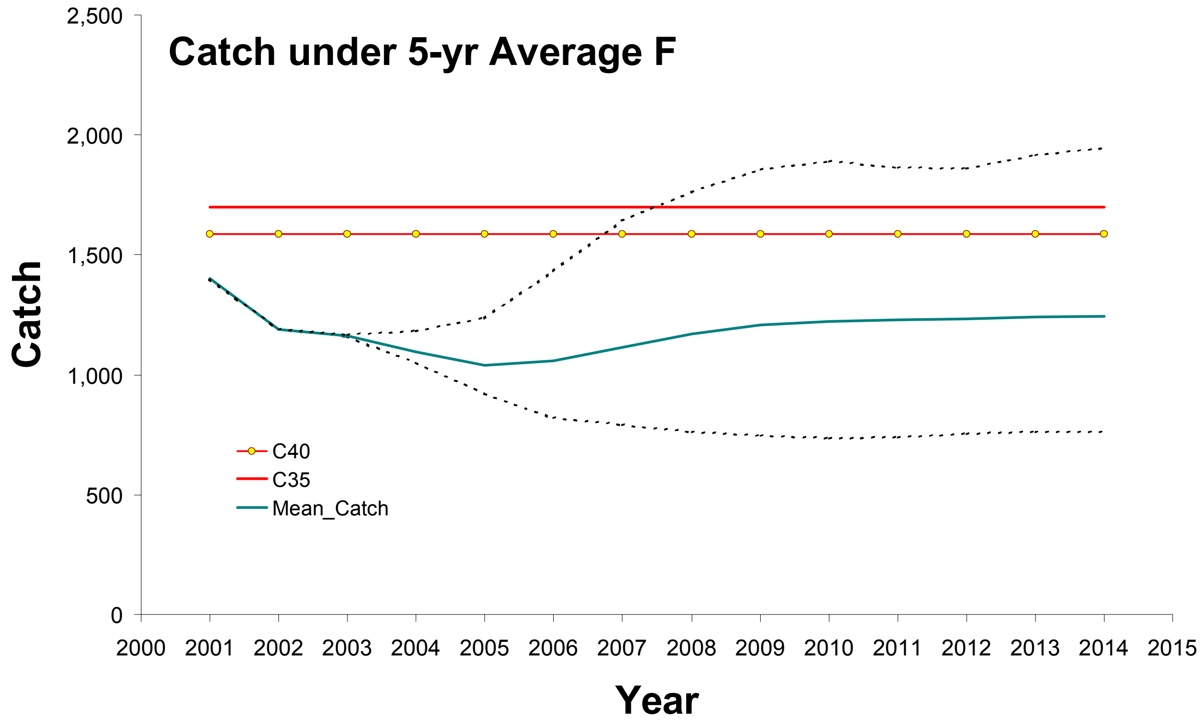


Figure 1.45. EBS walleye pollock female spawning biomass abundance trends, 1990-2006 as estimated by Model 1 and projections to 2006 at different catch strategies. Note that the F_{msy} catch levels are unadjusted. Horizontal solid and dashed lines represent the B_{msy}, and $B_{40\%}$ levels, respectively.



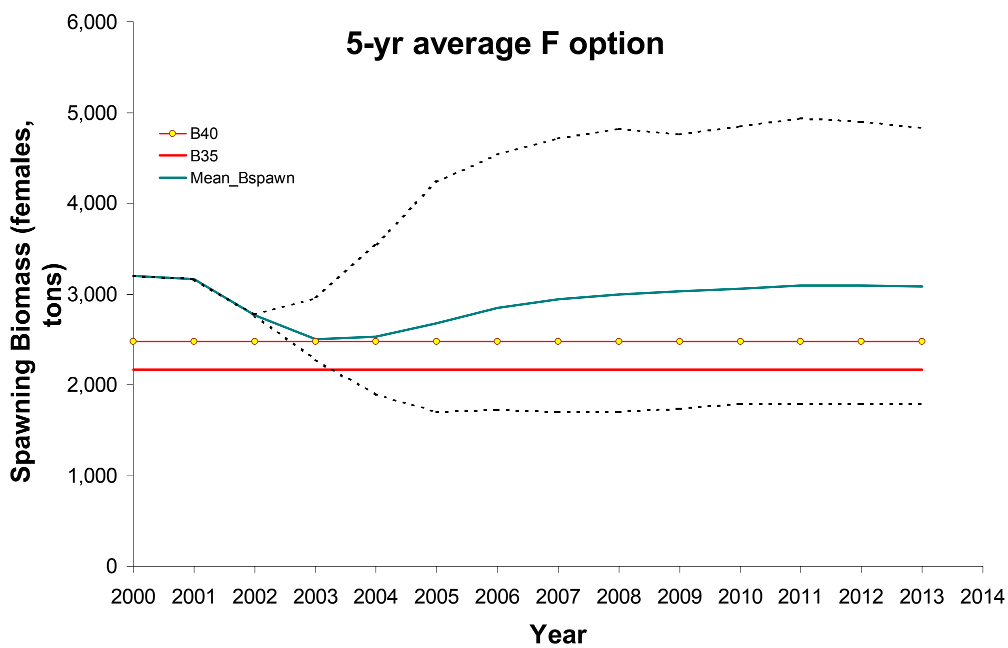


Figure 1.46. Projected EBS walleye pollock yield (top) and spawning biomass (bottom) under F equal to the mean value from 1997-2001 relative to the long-term expected values under $F_{35\%}$ and $F_{40\%}$ (horizontal lines) for Model 1.

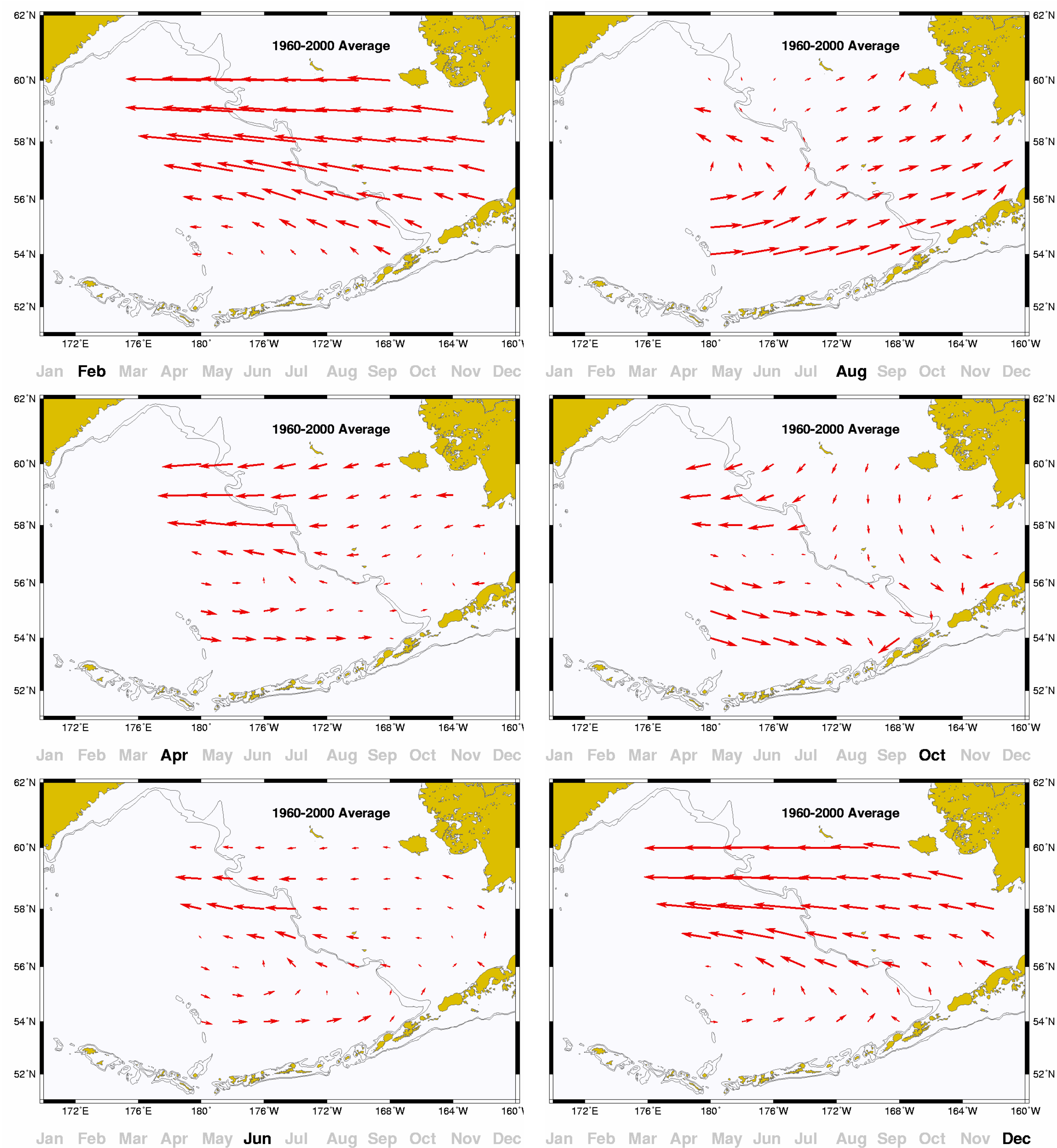


Figure 1.47. Average surface currents based on the OSCURS model, 1960-2000 for February, April, June, August, October and December.

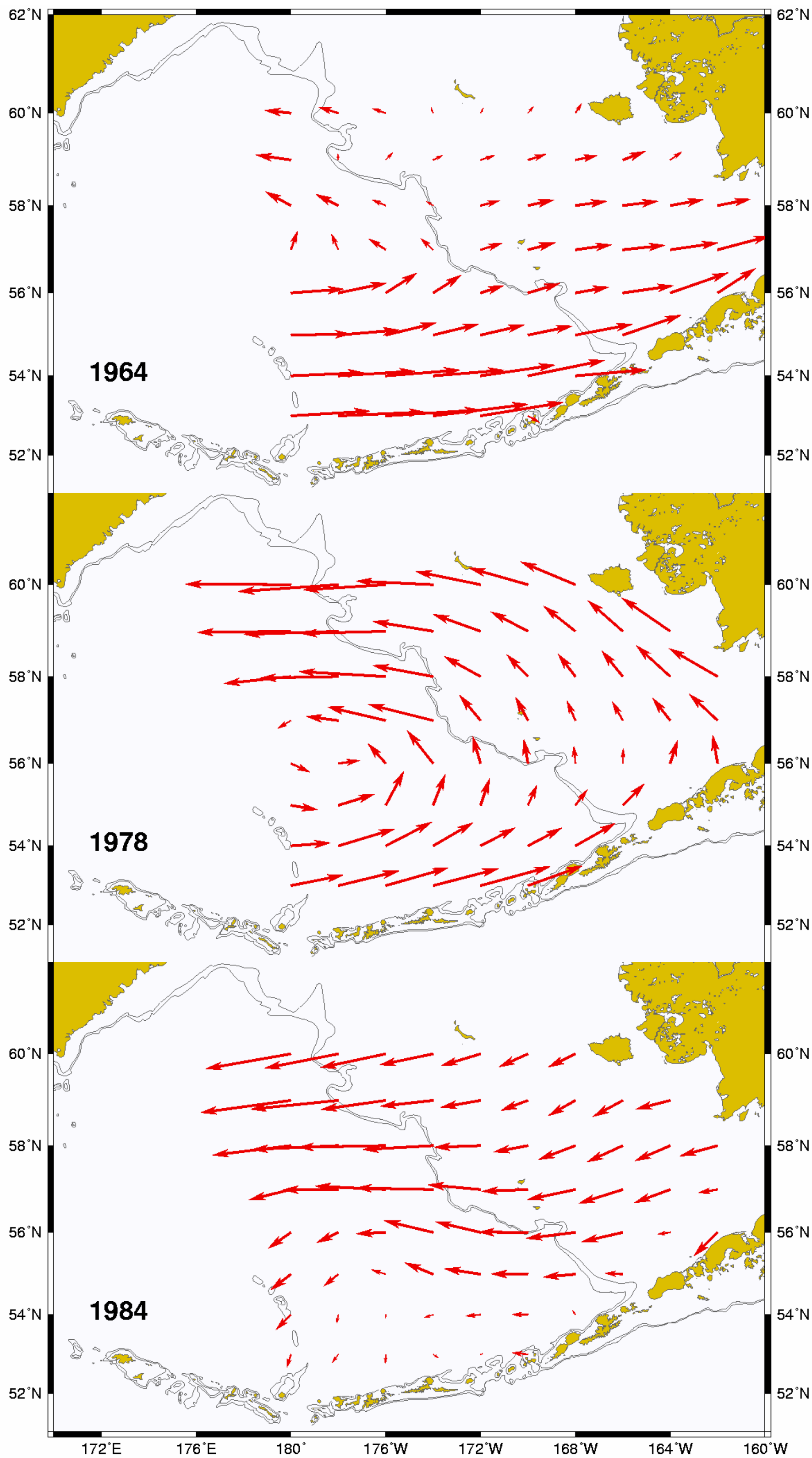


Figure 1.48. Average surface currents for **April** based on the OSCURS model in 1964, 1978, and 1984.

1.14. Model details

1.14.1. Model structure

We used an explicit age-structured model with the standard catch equation as the operational population dynamics model (e.g., Fournier and Archibald 1982, Hilborn and Walters 1992, Schnute and Richards 1995). Catch in numbers at age in year *t* ($C_{a,t}$) and total catch biomass (Y_t) were

$$
\begin{aligned}
C_{t,a} &= \frac{F_{t,a}}{Z_{t,a}}\left(1-e^{-Z_{a,t}}\right)N_{t,a}, && 1 \le t \le T \quad 1 \le a \le A \\
N_{t+1,a+1} &= N_{t,a}e^{-Z_{t,a}} && 1 \le t \le T \quad 1 \le a < A \\
N_{t+1,A} &= N_{t,A-1}e^{-Z_{t,A-1}} + N_{t,A}e^{-Z_{t,A}} && 1 \le t \le T \\
Z_{t,a} &= F_{t,a} + M_{t,a} \\
C_{t\cdot} &= \sum_{a=1}^{A} C_{t,a} \\
p_{t,a} &= C_{t,a} / C_{t\cdot} \\
Y_t &= \sum_{a=1}^{A} w_a C_{t,a} \text{ , and}
\end{aligned}
$$

where

T	is the number of years,
A	is the number of age classes in the population,
$N_{t,a}$	is the number of fish age *a* in year *t,*
$C_{t,a}$	is the catch of age class *a* in year *t,*
$p_{t,a}$	is the proportion of the total catch in year *t,* that is in age class *a,*
$C_{t\cdot}$	is the total catch in year *t,*
w_a	is the mean body weight (kg) of fish in age class *a,*
$Y_{t\cdot}$	is the total yield biomass in year *t,*
$F_{t,a}$	is the instantantaneous fishing mortality for age class *a,* in year *t,*
M_{ta}	is the instantantaneous natural mortality in year *t* for age class *a,* and
Z_{ta}	is the instantantaneous total mortality for age class *a,* in year *t.*

We reduced the freedom of the parameters listed above by restricting the variation in the fishing mortality rates ($F_{t,a}$) by assuming that

$$
\begin{aligned}
F_{t,a} &= s_{t,a}\mu^f \exp\left(\varepsilon_t\right) && \varepsilon_t \sim N\left(0,\sigma_E^2\right) \\
s_{t+1,a} &= s_{t,a}\exp\left(\gamma_{t,a}\right), && \gamma_{t,a} \sim N\left(0,\sigma_s^2\right)
\end{aligned}
$$

where

$s_{t,a}$	is the selectivity for age class *a* in year *t,* and

μ^F is the median fishing mortality rate over time.

If the selectivities ($s_{t,a}$) are constant over time then fishing mortality rate decomposes into an age component and a year component. This assumption creates what is known as a separable model. If selectivity in fact changes over time, then the separable model can mask important changes in fish abundance. In our analyses, we constrain the variance term (σ_s^2) to allow selectivity to change slowly over time–thus improving our ability to estimate the $\gamma_{t,a}$. Also, to provide regularity in the age component, we placed a curvature penalty on the selectivity coefficients using the squared second-differences. We selected a simple random walk as our time-series effect on these quantities. Prior assumptions about the relative variance quantities were made. For example, we assume that the variance of transient effects (e.g., σ_E^2) is large to fit the catch biomass precisely. Perhaps the largest difference between the model presented here and those used for other groundfish stocks is in how we model "selectivity" of both the fishery and survey gear types. The approach taken here assumes that large differences between a selectivity coefficient in a given year for a given age should not vary too much from adjacent years and ages (unless the data suggest otherwise). The magnitude of these changes is determined by the prior variances as presented above. Last year we investigated the sensitivity of model results with different prior variances for comparison.

In the SAM analyses, recruitment (R_t) represents numbers of age-1 individuals modeled as a stochastic function of spawning stock biomass. A further modification made in Ianelli et al. (1998) was to have an environmental component to account for the differential survival attributed to larval drift (e.g., Wespestad et al. 2000). (κ_t):

$$R_t = f\left(B_{t-1}\right)e^{\kappa_t + \tau_t}\ , \qquad \tau_t \sim \mathrm{N}\left(0,\sigma_R^2\right)$$

with mature spawning biomass during year *t* was defined as:

$$B_t = \sum_{a=1}^{15} w_a \phi_a N_{at}$$

and ϕ_a, the proportion of mature females at age, was the same as that presented in Wespestad (1995).

The environmental component is based on hypotheses about the relationship between surface advection during the post-spawning period (pollock egg and larval stages) and pollock survival. Wespestad et al. (2000) found that during years when the surface currents tended north-north westward along the shelf that year class strength was improved compared to years when currents were more easterly. They used the OSCURS model to simulate drift. In a subsequent analyses (Ianelli et al. 1998) their analysis was extended to apply within a stock assessment model context. The procedure is briefly outlined as follows:

1) run the OSCURS model for 90 days in each year starting at 165W and 55.5N storing the daily locations;

2) compute the average location of the simulated drifter over the 90 day period within each year using the GMT program (Wessel and Smith 1991) **`fitcircle`**.

3) plot these points and create a geographic grid (**A**) centered such that it covers all mean values over all years,

4) create an indicator matrix (Ψ) dimensioned such that the rows correspond to the number of years needed for the model (here 1964 – 1997) and the columns represent either the row or column index of the geographic grid. For example, say the average location of a drifter in 1980 fell within the bounds of the geographic grid cell represented by the 2nd column

and 4th row, then the indicator matrix would have 2 and 4 as entries for the row corresponding to 1980.

Submit the indicator matrix as data to be read in to the model so that the values of the geographic grid matrix can be estimated where:

$$\kappa_t = A\left(\Psi_{t,1}, \Psi_{t,2}\right), \qquad \kappa_t \sim \mathrm{N}\left(0, \sigma_\kappa^2\right) \quad .$$

The idea is simply that there are "good" circulation patterns and "bad" circulation patterns within the first few months after spawning.

Reparameterization of the stock-recruitment function

This year we implemented a reparameterized form for the stock-recruitment relationship as by Francis (1992). For the Beverton-Holt form we have:

$$R_t = f\left(B_{t-1}\right) = \frac{B_{t-1} e^{\varepsilon_t}}{\alpha + \beta B_{t-1}}$$

where

R_t is recruitment at age 1 in year *t,*

B_t is the biomass of mature spawning females in year *t,*

ε_t is the "recruitment anomaly" for year *t*,

α, β are stock-recruitment function parameters.

Values for the stock-recruitment function parameters α and β are calculated from the values of R_0 (the number of 0-year-olds in the absence of exploitation and recruitment variability) and the "steepness" of the stock-recruit relationship (*h*). The "steepness" is the fraction of R_0 to be expected (in the absence of recruitment variability) when the mature biomass is reduced to 20% of its pristine level (Francis 1992), so that:

$$\alpha = \tilde{B}_0 \frac{1-h}{4h}$$
$$\beta = \frac{5h-1}{4hR_0}$$

where

$\tilde{B}_0$ is the total egg production (or proxy, e.g., female spawner biomass) in the absence of exploitation (and recruitment variability) expressed as a fraction of R_0.

Some interpretation and further explanation follows. For steepness equal 0.2, then recruits are a linear function of spawners (implying no surplus production). For steepness equal to 1.0, then recruitment is constant for all levels of spawning stock size. A value of *h* = 0.9 implies that at 20% of the unfished spawning stock size will result in an expected value of 90% unfished recruitment level. Steepness of 0.7 is a commonly assumed default value for the Beverton-Holt form (e.g., Kimura 1988).

In Ianelli et al. (1999) we assumed the expected value of steepness was 0.7 with a 20% coefficient of variation. The prior distribution was assumed to be lognormal within the range 0.2-1.0. Clearly, alternative values could be applied, particularly in the sense of taking the experience among other fish stocks (e.g., Lierman and Hilborn (1997)). Since we include a stock-recruitment curve as an integrated part of the assessment, assumptions about prior parameter values are critical, particularly if the data are non-informative. This feature also allows for computation of F_{msy} values and related quantities such as MSY, B_{msy} etc (see section 1.14.2 below). In the year 2000, one aspect of the review (Appendix 3) pointed out:

> *"Priors need to be described, explained and justified—and ideally need to be supplied by a range of "experts" rather than a single analyst."*

In response to this, we selected a compromise situation whereby we examined results on slope-at-the-origin values obtained for other gadids around the world and pooled them to illicit a more reasonably defensible prior distribution. This work is continuing and has not been fully implemented in this assessment (a new functional form for the prior distribution is used, the beta distribution, but set up to be similar to the prior distribution in the last assessment). In the models presented in Ianelli et al. (2000), they conducted sensitivity to the effect of using completely uninformative prior distributions as an alternative.

To have the critical value for the stock-recruitment function (steepness, h) on the same scale for the Ricker model, we begin with the parameterization of Kimura (1990):

$$R_t = f\left(B_{t-1}\right) = \frac{B_{t-1} e^{a\left(1-\frac{B_{t-1}}{\varphi_0 R_0}\right)}}{\varphi_0} .$$

It can be shown that the Ricker parameter *a* maps to steepness as:

$$h = \frac{e^a}{e^a + 4}$$

so that the prior used on h can be implemented in both the Ricker and Beverton-Holt stock-recruitment forms. Here the term φ_0 represents the equilibrium unfished spawning biomass per-recruit.

Parameter estimation

The objective function was simply the product of the negative log-likelihood function and prior distributions. To fit large numbers of parameters in nonlinear models it is useful to be able to estimate certain parameters in different stages. The ability to estimate stages is also important in using robust likelihood functions since it is often undesirable to use robust objective functions when models are far from a solution. Consequently, in the early stages of estimation we use the following log-likelihood function for the survey and fishery catch at age data (in numbers):

$$f = n \cdot \sum_{a,t} p_{at} \ln\left(\hat{p}_{at}\right) ,$$

$$p_{at} = \frac{O_{at}}{\sum_a O_{at}}, \qquad \hat{p}_{at} = \frac{\hat{C}_{at}}{\sum_a \hat{C}_{at}}$$

$$\hat{C} = C \cdot E_{ageing}$$

$$E_{ageing} = \begin{pmatrix} b_{1,1} & b_{1,2} & b_{1,3} & \cdots & b_{1,15} \\ b_{2,1} & b_{2,2} & & & \\ b_{3,1} & & \ddots & & \\ \vdots & & & \ddots & \\ b_{15,2} & & & & b_{15,15} \end{pmatrix} ,$$

where *A,* and *T,* represent the number of age classes and years, respectively, *n* is the sample size, and $O_{at}, \hat{C}_{at}$ represent the observed and predicted numbers at age in the catch. The elements $b_{i,j}$ represent ageing mis-classification proportions are based on independent agreement rates between otolith age readers. For model runs presented above, we assumed that ageing error was insignificant. Sample size values were fixed at 100 for the fishery data, 50 for the bottom trawl survey, and 25 for the EIT survey. Strictly speaking, the amount of data collected for this fishery indicates higher values might be warranted. However, it is well known that the standard multinomial sampling process is not robust to violations of assumptions (Fournier et al. 1990). Consequently, as the model fit approached a solution, we invoke a robust likelihood function which fit proportions at age as:

$$\prod_{a=1}^{A} \prod_{t=1}^{T} \frac{\left(\exp\left\{ -\frac{\left(p_{t,a} - \hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a} + 0.1/T\right)\tau^2} \right\} + 0.01 \right)}{\sqrt{2\pi\left(\eta_{t,a} + 0.1/T\right)\tau}}$$

Taking the logarithm we obtain the log-likelihood function for the age composition data:

$$-1/2 \sum_{a=1}^{A} \sum_{t=1}^{T} \log_e\left(2\pi\left(\eta_{t,a} + 0.1/T\right)\right) - \sum_{a=1}^{A} T \log_e(\tau)$$
$$+ \sum_{a=1}^{A} \sum_{t=1}^{T} \log_e\left[\exp\left\{ -\frac{\left(p_{t,a} - \hat{p}_{t,a}\right)^2}{2\left(\eta_{t,a} + 0.1/T\right)\tau^2} \right\} + 0.01 \right]$$

where $\eta_{t,a} = \hat{p}_{t,a}\left(1 - \hat{p}_{t,a}\right)$

and $\tau^2 = 1/n$

gives the variance for $p_{t,a}$

$$\left(\eta_{t,a} + 0.1/T\right)\tau^2 .$$

Completing the estimation in this fashion reduces the model sensitivity to data that would otherwise be considered "outliers."

We assumed that the survey was completed at the beginning of the year (prior to the fishery). Survey numbers account for removals that occurred during the first part of the year (since surveys occur during the summer months). As in previous years, we assumed that removals by the survey were insignificant (i.e., the mortality of pollock caused by the survey was considered insignificant). Consequently, a set of analogous catchability and selectivity terms were estimated for fitting the survey observations as:

$$\hat{N}^s_{t,a} = e^{-0.5Z_{t,a}} N_{t,a} q^s_t s^s_{t,a}$$

where the superscript *s* indexes the type of survey (EIT or BTS). For these analyses we chose to keep survey catchabilities constant over time (though they are estimated separately for the EIT and bottom trawl surveys). The contribution to the negative log-likelihood function from the surveys is given by

$$\sum_{t^s} \left(\frac{\ln\left(A^s_{t\cdot} / \hat{N}^s_{t\cdot} \right)^2}{2\sigma^2_{t^s}} \right)$$

where $A^s_{t\cdot}$ is the total (numerical) abundance estimate with variance $\sigma^2_{t^s}$ from survey *s* in year *t*.

The contribution to the negative log-likelihood function for the observed total catches ($O_{t\cdot}$) by the fishery is given by

$$\lambda_c \sum_t \left(\log\left(O_{t\cdot} / \hat{C}_{t\cdot} \right)^2 \right)$$

where λ_c represents prior assumptions about the accuracy of the observed catch data. Similarly, the contribution of prior distributions (in negative log-density) to the log-likelihood function include

$\lambda_\varepsilon \sum_t \varepsilon_t{}^2 + \lambda_\gamma \sum_{ta} \gamma_{t,a}{}^2 + \lambda_\delta \sum_t \delta_t{}^2$ where the size of the *λ's* represent prior assumptions about the variances of these random variables. For the model presented below, over 698 parameters were estimated. Most of these parameters are associated with year-to-year and age specific deviations in selectivity coefficients. For a presentation of this type of Bayesian approach to modeling errors-in-variables, the reader is referred to Schnute (1994). To easily estimate such a large number of parameters in such a non-linear model, automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries was used. This software provided the derivative calculations needed for finding the posterior mode via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gave simple and rapid access to these routines and provided the ability estimate the variance-covariance matrix for all dependent and independent parameters of interest.

1.14.2. Solving for F_{msy} in an integrated model context

Recruitment in year *i* is given by the Beverton-Holt model

$$R_i = \frac{S_{i-1} e^{\varepsilon_i}}{\alpha + \beta S_{i-1}} \quad ,$$

and for the Ricker model as

$$R_i = S_{i-1} e^{\alpha - \beta S_{i-1} + \varepsilon_i}$$

where

R_i is recruitment at age 3 in year *i,*

S_i is the biomass of females spawning in year *i,*

ε_i is the "recruitment anomaly" for year *i*,

α, β are stock-recruitment function parameters.

Since ϕ (see below) is the expected female spawning biomass produced by a single recruit, then at equilibrium we have for the Beverton-Holt Model:

$R_{eq} = \dfrac{R_{eq}\phi}{\alpha + \beta R_{eq}\phi}$. Solving for R_{eq} gives

$$R_{eq} = \frac{(\phi\text{-}\alpha)}{\beta\phi},$$

similarly, for the Ricker model one obtains

$$R_{eq} = \frac{\ln(\phi) + \alpha}{\beta\phi}$$

with

$$\phi = \sum_{j=1}^{15+} W_j N_j s_j f_j$$

$$N_j = 1 \qquad j = 1$$

$$N_j = N_{j-1}s_{j-1} \quad 1 < j \leq 25$$

Note that the survival rate, s_j, and proportion mature females, f_j, are age specific. Equilibrium yield (*Y*) is computed for a given exploitation rate (*F*), giving $Y = F \cdot \overline{B}$ where $\overline{B}$ is the average equilibrium exploitable biomass. Solving for the MSY simply involves determining the exploitation rate where yield is maximized. Analytical methods are commonly used to find this value by taking the first derivative with respect to *F,* setting the result equal to zero, and solving for *F.* Unfortunately, such analytical methods are not readily available for common forms of stock-recruitment functions used in fisheries with non-trivial age-specific selectivities. Here we implement a numerical method which solves for MSY and can be applied to a broad family of models. The method implements the Newton-Raphson technique for finding the root of an equation (here, the first derivative of yield). The steps are outlined as:

1) pick a trial *F* and evaluate the equilibrium yield, *f(F)*;
2) compute the first and second derivatives of yield wrt *F*;
3) update original trial *F* from 1) by subtracting the ratio $\dfrac{f'(F)}{f''(F)}$
4) repeat steps 1) – 3) a fixed number of times so that the final adjustment in step 3) is very small. Note, convergence is usually implemented through the use of some sort of tolerance level. However, in our case we wish maintain differentiability, therefore we use a fixed number of iterations.

In practice, finite difference approximations for the derivatives given above appear to work satisfactorily which further improves one's ability to implement this type of algorithm. That is, let

$f'(F) = \dfrac{f(F+d) - f(F-d)}{2d}$ and $f''(F) = \dfrac{f(F+d) - 2f(F) + f(F-d)}{d^2}$ where *d* is some small value, say $1\text{x}10^{-7}$.

1.15. Aleutian Island Region Pollock

In 1997 we presented an updated analysis of the age-structured information available for the Aleutian Islands Region. Geographically, there are questions as to the appropriateness of defining pollock caught in the "Aleutian Islands" region as being from a separate stock. From this early analysis, it was clear that removals from this area are potentially from the EBS stock. Therefore, interpretations of the results raised many important questions.

The 2000 Aleutian Island bottom trawl survey estimated biomass at 105.5 thousand t, a 13% increase over the 1997 survey estimate of 93.5 thousand t (Table 1.19). Surveys from this region indicate that the biomass peaked in 1983 and declined to the 1994 level. The 1994 survey indicated a strong mode of either age 1 or 2 pollock—the 1992 or 1993 year-class. These fish appeared to have entered the fishable population in 1996 and have stabilized or increased pollock biomass in the Aleutian Islands in recent years.

Table 1.19. Pollock biomass estimates from the Aleutian Islands Triennial Groundfish Survey, 1980-2000.

	Aleutian Islands and Unalaska-Umnak area (~165W-170W)	Aleutian Region (170E-170W)
1980	308,745	252,013
1983	778,666	495,982
1986	550,517	448,138
1991	218,783	167,140
1994	117,198	77,503
1997	158,912	93,512
2000	133,366	105,554

Catch-age data are relatively scarce for pollock caught in the Aleutian Islands region; the data that are available come primarily from the eastern area (INPFC area 541). Trawl survey data show that most of the biomass is located in the eastern Aleutian Islands and along the north side of Unalaska-Umnak islands in the eastern Bering Sea region (Fig. 1.49). The stock definition for "Aleutian Islands pollock" is therefore confounded with Bering Sea abundance levels and abundance in the Aleutian Basin. We therefore consider pollock in the Aleutian Island region as an operational "stock" for management with biomass levels on the order of 100 - 200 thousand tons (for age 3 and older). In the past two years, harvest levels in this region have only been about 1,000 tons with no directed pollock fishing allowed.

It seems unlikely that pollock in the eastern Aleutian Islands represent a discrete stock, since pollock are continuously distributed from the eastern Bering Sea. In prior assessments it was assumed that stock dynamics in the Aleutian Islands are similar to that of eastern Bering Sea pollock and the biomass trend the same. Analyses on MSY values for Aleutian Islands pollock were not pursued given, among other things, potential problems with stock definition and paucity of data for this region.

Although limited a number of age-structured model runs were done on this stock in the past, the results showed a large degree of ambiguity. Consequently, until the issues of stock definition and survey interpretation are resolved, we recommend continuing the use of the most recent survey biomass estimate applied to an adjusted natural mortality. This gives an ABC based on Tier 5 (2000 survey biomass × M × 0.75) of **23,750 t** at a biomass of 105,554 t (with $M = 0.3$). The OFL based on Tier 5 (2000 survey biomass × M) gives **31,666 t**.

	1997	1998	1999	2000	2001	F
F_{ABC}	17,413 – 28,000 t	23,760 t	23,760 t	23,760 t	**23,750** t	0.225 = 0.75 M
F_{OFL}	24,000 – 38,000 t	31,680 t	31,680 t	31,680 t	**31,666** t	0.3 = M

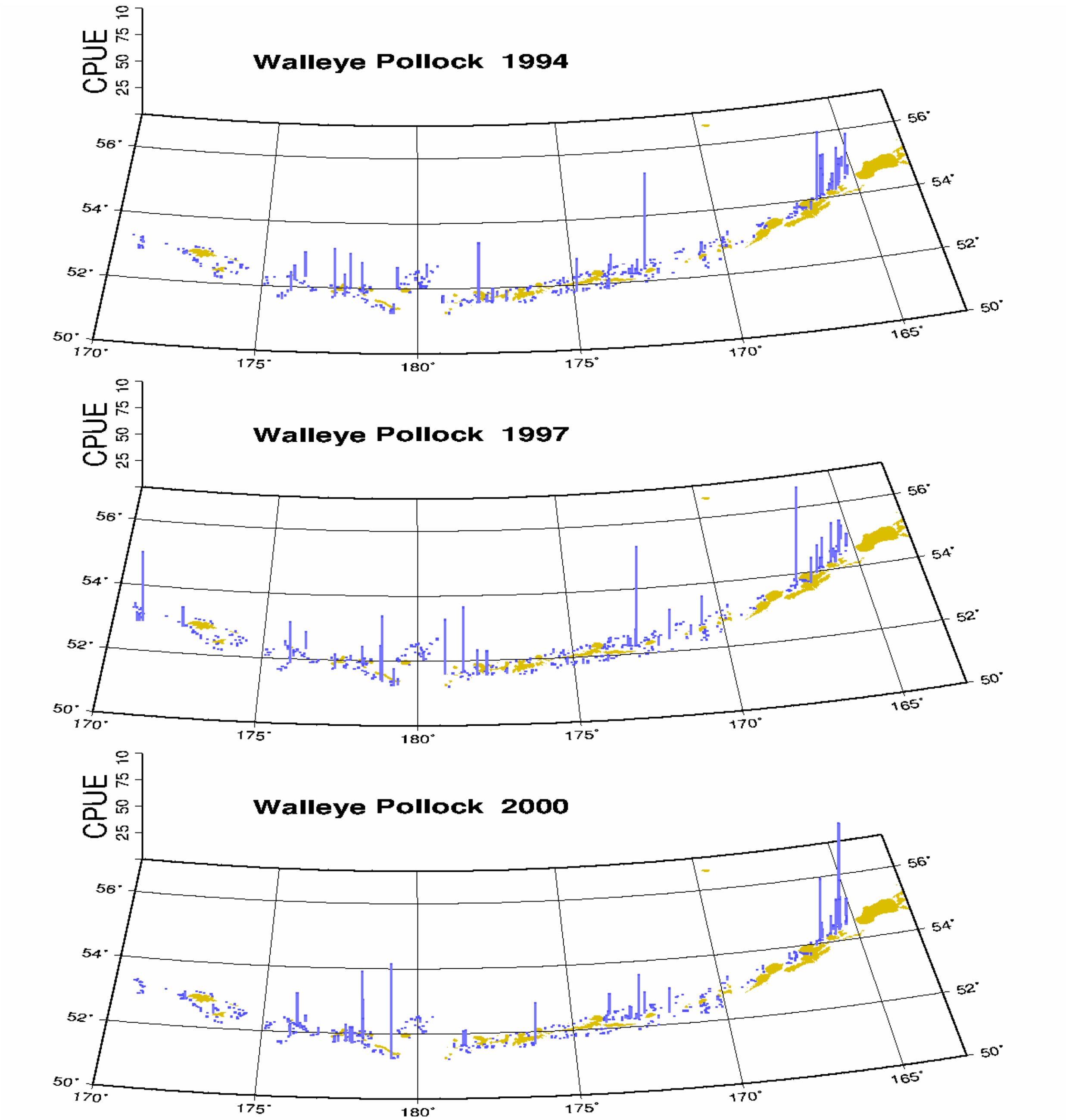


Figure 1.49. NMFS survey distributions of pollock in the Aleutian Islands region, 1994, 1997, and 2000. The height of the vertical bars is proportional to survey station pollock catch rate.

1.16. Aleutian Basin-Bogoslof Island Area

In 1999 the Plan Team requested that we present 3 alternative methods for computing ABC values for the Bogoslof region. They included:

1. The same method as in past years (with 2,000,000 ton estimate for $B_{40\%}$)
2. A simplified age-structured model based on recent Bogoslof population trends (not updated since Ianelli et al. (1999)
3. The same method as is currently used for the Aleutian Islands region (i.e., Tier 5, F_{ABC} =0.75*M)

The Council SSC considered the age-structured model to be inappropriate since it covers only part of the stock and concurred with the Plan Team on placing Bogoslof pollock in Tier 5. They also recommend reducing the ABC value further based on the historical target for biomass in this region (2 million tons). This year we present these two calculations for estimating the ABC for this region.

The information available for pollock in the Aleutian Basin and the Bogoslof Island area indicates that these fish belong to the same "stock". The pollock found in our surveys are generally older than age 5 and are considered distinct from eastern Bering Sea pollock. Data on the age structure of Bogoslof-Basin pollock show that a majority of pollock in the Basin originated from year-classes that were also strong on the shelf, 1972, 1978, 1982, 1984, 1989, and 1992. Recent research suggests that there are strong year-classes appearing on the shelf that have not been coincidentally as strong (in a relative sense) in the Bogoslof region (Fig. 1.50). The conditions leading to strong year-classes of pollock in the Basin appears to be density related and may be functionally related to abundance on the shelf.

Differences in spawning time and fecundity have been documented between eastern Bering Sea pollock and Aleutian Basin pollock. Pollock in the northern shelf have a similar size at age as Aleutian Basin pollock although a very different age composition. However, Aleutian Basin pollock may not be an independent stock. Very few pollock younger than 5 years old have ever been found in the Aleutian Basin including the Russian portion. Recruits to the basin are coming from another area, most likely the surrounding shelves either in the US or Russian EEZ.

1.16.1. ABC estimates for Bogoslof area

Aleutian Basin pollock spawning in the Bogoslof Island area have been surveyed annually since 1988. Pollock harvested in the Bogoslof Island fishery (Area 518) have noticeably different age compositions than those taken on the eastern Bering Sea shelf (Wespestad and Traynor 1989). The following survey results show that population decline occurred between 1988 and 1994, and then increased in 1995. The movement of pollock from the 1989 year-class to the Bogoslof Island area was partly responsible for the 1995 increase, but the abundance of all ages increased between 1994 and 1995. The decrease between 1995 and 1996 was followed by a continued decline in 1997. This suggests that the 1995 estimate may have been over-estimated, or that conditions in that year affected the apparent abundance of pollock. The current population levels on the eastern Bering Sea shelf, and the absence of extremely large year-classes, suggests that pollock abundance will not increase significantly in the Bogoslof area in the coming years. A summary report of the 2001 survey is attached (Appendix 1) with summary Bogoslof Island EIT survey biomass estimates, 1988-2001, as follows:

Biomass (million t)													
1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
2.4	2.1	-	1.3	0.9	0.6	0.49	1.1	0.68	0.39	0.49	0.48	0.30	0.232

Tier 5 computations use the most recent survey biomass estimate applied to an adjusted natural mortality. This gives an ABC (2001 survey biomass × M × 0.75) of **34,800 t** at a biomass of 232,000 t (with $M = 0.2$). The OFL is **46,400 t**.

Given the survey estimate of exploitable biomass of 0.232 million t and M = 0.2 and based on the SSC discussions for further reductions in ABC based on considerations of a target stock size of 2 million tons, the F_{ABC} recommendation is computed as:

$$F_{abc} \leq F_{40\%} \times \left(\frac{B_{2001}}{B_{40\%}} - 0.05 \right) \Big/ (1 - 0.05) = 0.27 \times \left(\frac{232,000}{2,000,000} - 0.05 \right) \Big/ (1 - 0.05) = 0.0188$$

Using a fishing mortality rate of 0.019 translates to an exploitation rate of 0.019 which when multiplied by 232,000 t, gives a **2001 ABC of 4,310 t for the Bogoslof region.**

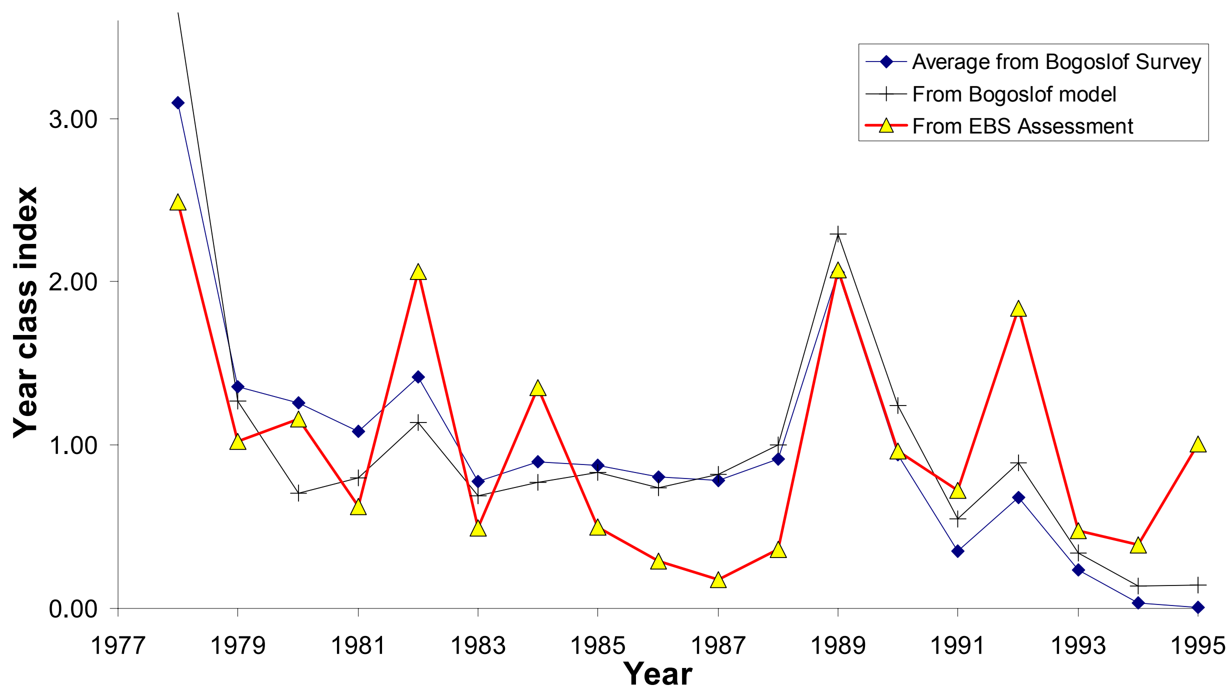


Figure 1.50. Relative year-class strengths (normalized to have a mean value of 1) for pollock as observed (averaged) from the Bogoslof EIT surveys and from a simple age-structured model for the Bogoslof Island stock compared with those observed from the main EBS pollock stock assessment model.